LAND DEVELOPMENT HANDBOOK

THIRD EDITION

Planning, Engineering, and Surveying

Dewberry®

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PLANNING, ENGINEERING, AND SURVEYING

Dewberry®

Editor-in-Chief: Sidney O. Dewberry
Coordinating Editor: Lisa N. Rauenzahn

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To the hardworking Dewberry employees who dedicate their talent, energy, and passion to building amazing places.

Ours is a business in which a great deal of what we do has a visible and tangible impact on the world. I love driving past the places our firm has had a hand in creating. Conference centers. Housing developments. Lakes. Golf courses. Libraries. Churches. Bridges. Roads. Telecommunications facilities. Small or large, they're all something to be proud of. Such landmarks also provide a satisfying reminder: when it comes to measuring the land, reshaping it, getting across it or building on it, Dewberry has done it—and done it well—for a half century.

—Sidney O. Dewberry
The Dewberry Way: Celebrating 50 Years of Excellence, *13 April 2006*

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Gary Nickerson, PE; Updated/Revised: Charlie C. Crowder, Jr.

FOREWORD

Details often make the difference between the ordinary and the extraordinary.

—Todd Mansfield

Over the years I've worked on many sides of the land development industry. Whether approaching land development from a design, policy, or conservation perspective, the underlying motivation in my experience has always been the same: we are in the business of building vibrant and sustainable communities. Realizing this objective, however, is no small task—it requires visionary leaders and developers, innovative designers and builders, and progressive policy makers who are all committed to a common objective: creating a sense of place.

Sid Dewberry's enduring accomplishments in responsible and creative land development underscore this type of commitment. In this publication, Sid leads his staff of dedicated experts and industry colleagues in a truly collaborative effort to present an updated version of the *Land Development Handbook,* which I commend to your reading.

The truly comprehensive nature of this book provides unique insights to an array of issues ranging from the various aspects of technical design to the rezoning process. What's more, the collective experience of Dewberry is distilled to offer proven perspective on where we've been, what we struggle with today, and how we can begin to prepare for future land development challenges. The third edition of the *Land Development Handbook* strikes a thoughtful balance between the science of city building and the art of placemaking. In particular, this edition aptly places land development issues in the larger context of our stewardship over the natural and built environment. New materials in this edition include:

- Updates in the environmental chapters to reflect current regulations, standards of practice, and permitting requirements
- Enhancements to the technical infrastructure and planning chapters, which include a useful discussion of green building certification, specifically addressing aspects related to site selection and design
- Refinements to the surveying chapters to reflect the extensive use of modern technologies such as GIS and GPS for data collection, design, presentations, marketing, and maintenance purposes
- New case studies that not only represent traditional suburban residential development, but exemplify recent market attention to mixed-use infill projects and urban redevelopments

The market factors prompting these updates have created a need for products addressing specific design challenges, many of which differ from conventional aspects of land development. For example, by integrating environmental considerations throughout the design process outlined in the book, this topic becomes more than a side note—it becomes a design imperative. To accommodate such changes in the development world, professionals need an updated, comprehensive reference to help them remain competitive in this dynamic industry. Accordingly, Dewberry has transformed the text into a forward-looking guide aligned with the twenty-first century development climate—one where the environment, security, and a sense of community take an even greater precedence.

I offer my congratulations to Sid and Dewberry on the completion of this third edition of the *Land Development Handbook,* and recommend this comprehensive work to any professional seeking to stay ahead of the continually evolving face of land development.

Todd W. Mansfield
Chairman
Urban Land Institute
December 2007

ABOUT THE AUTHOR

DEWBERRY, headquartered in Fairfax, Virginia, is an A/E firm operating in 18 states. It was rated by *Building Design and Construction* magazine as one of the top 20 commercial design firms, and routinely appears in *Engineering News-Record*'s annual list of the top 50 design firms.

PREFACE

When this business was launched more than 50 years ago, land development planning, engineering, and surveying was largely a backwater branch of civil engineering and not respected as a legitimate engineering field. Other consultants looked down their noses at anyone engaged in this practice and felt it was not real engineering. Since land development consulting was how I made a living, I resented the notion. I feel now, and felt then, that this is a very noble profession. It requires expertise in all branches of civil engineering including surveying, roadway design, grading, drainage, water systems, wastewater systems, dry utilities, and environmental science as well as knowledge of the related fields including urban planning, landscaping, archaeology, and architecture. More important than the broad-based civil engineering experience gained as a land development consultant is the end product of our diligent labor: land development consultants provide housing (shelter) for people—one of the absolute necessities of humankind, along with food and clothing.

For these reasons, I have devoted a large part of my career to elevating this profession to the level it deserves. Our firm tried hard to influence our clients to allocate a larger portion of the cost of a housing or commercial project to much-needed infrastructure. In those early days, few regulations required adequate drainage, utilities, and other infrastructure in order to provide good, reliable access to housing and other real estate developments. We often clashed with our clients over these issues. Gradually and over time, the localities mandated better infrastructure and improved environmental performance through enhanced standards and regulations. These requirements are still progressing and evolving today, as evidenced by the tremendous strides taken in the green building and environmental movements. I feel that our firm, in its way, without crossing swords too much with our clients, has contributed hugely to an improved built environment for the purposes of everyday living.

We started a journey a half century ago and we have arrived at the destination. The profession of land development consulting is now recognized and respected among the engineering disciplines. Every major A/E consulting firm has a land development practice. It is taught in many colleges and universities as an elective and, in some cases, as its own specialty track within the civil engineering program. Young people are aware of and attracted to the profession. They enter this field inspired, bringing with them new ideas, the most recent technology, and a youthful perspective on the world that challenges us "old-timers" to keep pace with the speed of learning, rise above convention, and truly innovate for the benefit of our clients and our communities.

One of the ways by which Dewberry remains attuned to this dynamicindustry is through this book. The *Land Development Handbook* began as a dream many years ago. In the mid-1980s I decided we may as well just do it. I naively thought a book was something you sat down to do and finished in a few weeks. How surprising it was to learn that it would take years. The first edition took seven years from start to finish. When looking for a publisher I was very pleasantly surprised that we would not have to go to the expense of publishing this ourselves. All of the premiere technical publishers were anxious to publish and sell the book themselves. With McGraw-Hill Professional, we entered into what has become one of the most treasured and unique business relationships I have formed over the years. McGraw-Hill told us they would want us to update the handbook every few years—if the book was successful. Selling 5000 copies would represent an overwhelming success. By that measure, the handbook is a best seller and a tremendous point of pride for me and for Dewberry.

I want to thank everyone who contributed to the third edition. Having been through this process twice before, I know the success of this exciting Dewberry endeavor is due to the dedication of each team member. The third edition truly represents a corporate-wide effort, as nearly all of our 35 offices have contributed in small and large ways to the update. This diverse corporate presence has yielded valuable insight and fresh perspective. In addition to the core Dewberry staff, I want to thank the industry experts on the team—Megan Bramble of RLLS, Charlie Crowder of AEM Corp., Terry Ryan of ESI, and Don Wilson of Land and Boundary Consultants. We could not have done this without you.

Lisa Rauenzahn, PE, LEED AP, was the driving force behind this third edition. Lisa is one of the young, inspired engineers leading Dewberry proudly into the twenty-first century. Joining Dewberry after graduating from Duke, she has been an engineer in our Fairfax and Baltimore site-civil groups for over five years. Her enthusiasm for land development is evident in her writing and her work, several projects of which have won Dewberry Awards for excellence. Acting as the coordinating editor, she oversaw the efforts of the many contributors, authored or revised several chapters herself, coordinated the details with McGraw-Hill, and spearheaded the corporate effort to produce the new color signature sections. Lisa's tremendous leadership and willingness to reach out to her peers took this book outside of our Fairfax headquarters to many of the branch offices that were involved for the first time. Her persistence and commitment to the task never faltered. Through her diligent efforts, this book was delivered on time (in record time, just over one year!) and under budget. While I'm very proud of Lisa and the work she has done and am certainly grateful for all of her help with this particular project, I am most impressed with her passionate approach to the business of land development. She is not afraid to ask the difficult questions. She has challenged me and her peers to think carefully, critically, and creatively about the work we are doing and the way we go about doing it. How can we design better, for every client, on every project, in each community? How can we modify our business model to be green, be profitable, and be stewards, leaders, and role models in this competitive industry for the next 50 years? I have faith that with Lisa's help and the many other committed and passionate individuals that she is rallying to the task, we will answer these questions for Dewberry and many clients to come.

I want to extend a personal thank-you to Dottie Spindle, my administrative assistant, who takes care of the little things, the big things, and everything in between so that I can focus on the things that truly matter to me, like this book and this company. Keeping me on schedule and on task is a challenge, but it is one she embraces with a smile. I would also like to say thank you to Melody Patrick and the administrative assistants in the Baltimore office, who took Lisa into their family and helped her to take care of the many things that she inherited from me as part of this project. And a special thanks to Debbi Ishmael for her word-processing skills, her patience, and her willingness to make sure the final book product was in excellent shape.

This third edition wouldn't have been possible without the help of Doug Fahl, Chris Champagne, Bill Fissel, Gary Kirkbride, and Mike Snyder—the land development "champions" at Dewberry. As managers of land development business units, these men deal with the details—the clients, the projects, the staff, the issues, opportunities, and solutions. Collectively, with Lisa, they served as the book advisory board and helped craft the overall vision for the third edition. They rallied their staff to the cause, supporting the corporate-wide effort to take this book into the twenty-first century.

Peer reviewers are a critical component of our text. Those who think writing is difficult should try peer reviewing (or editing): balancing criticism with encouragement is a tall task. Our peer reviewers rose to this task within tight time frames and across great distances. Their expertise was invaluable, and that they were willing to lend it to this endeavor speaks highly of their commitment to Dewberry, to their practice, and to mentoring others. Thank you to Mike Shepp of the Ranson, West Virginia, office, who reviewed the survey chapters; Ileana Ivanciu of the Parsippany, New Jersey, office, who reviewed the environmental chapters; Gary Kirkbride of the Manassas, Virginia, office, who reviewed the planning chapters; Craig Thomas of the Fairfax, Virginia, office, who reviewed the Real Property Law chapter; Gary Nickerson of the Fairfax, Virginia, office, who reviewed the Water Supply and Treatment appendix; Doug Frost, of the Fairfax, Virginia, office, who reviewed the Soils appendix; Jeff Chapin, of the Fairfax office, who reviewed the Wastewater Treatment appendix; and Bill Springer, also of the Fairfax office, who reviewed the Floodplain Studies, Storm Drainage Design, Stormwater Management Design, and Stream Restoration chapters. Special thanks to John Denniston of McCormick Taylor (Baltimore), Timothy Schulze of Stantec (Rochester), and Donna and Ted Whitney of Geomatic Science, Inc. (Denver) for their input as well.

I would like to extend my sincere gratitude to all of our clients for your continued support. Many of you have willingly offered components of your projects for inclusion in the text, and we are happy to have your cooperation in this unique project. In particular I would like to acknowledge Mike Collier and Uniwest for allowing us to highlight Merrifield Town Center. We wanted a project that reflected today's market, today's challenges, and today's solutions. Your project fit the bill, and we couldn't be more pleased to have been part of the team that took your vision from plan to reality.

While I am grateful to all the authors who offered up their expertise and experience, I would be remiss not to recognize those who excelled under unusual or constrained conditions. They include authors who tackled multiple chapters—Stephanie Perez, Andrea Burk, Skip Notte, and Leo Segal; authors who wrote from scratch—Cash Davidson, Dan Pleasant, Paul Makowski, and Lisa Rauenzahn; and authors who came through at the last minute—Dave Bausmith, Leo Segal, and Dave Taylor.

Another young engineer who contributed greatly to the update is Hussein Shaban, an intern in the Fairfax site-civil group. A second-year civil engineering student, Hussein worked over the summer and part-time during the school year helping Lisa and the authors update and produce all the graphics. He tirelessly tracked and pursued the numerous permissions required in a text of this size. For a person of his age and limited experience, he demonstrated outstanding organizational ability and a genuine desire to learn. We wish Hussein the best of luck with his studies and look forward to working with him in the future. I'd also like to thank several other young engineers—Elizabeth Squires, Cody Pennetti, and Monet Lea—for helping Lisa during the final production stages.

Bart Rowe, Dewberry's controller, and Craig Thomas, Dewberry's corporate counsel, are my system of checks and balances—literally and figuratively! Bart worked with Lisa to track the book budget, procure paid permissions, and ensure proper accounting of the book effort. Craig helped us to initiate this project with McGraw-Hill, oversaw all of the contractual arrangements with the contributors, reviewed and monitored the permission needs in conjunction with Hussein and Lisa, and has been a valuable legal resource throughout. Thank you both for your support in this endeavor.

Land development projects, processes, designs, and decisions are rarely black-and-white; in fact, they are filled with colorful characters, interesting dilemmas, new opportunities, and innovative solutions. In keeping with the industry, this edition of the handbook has moved to color as well. Thanks to Steve Bozik, director of creative services for corporate marketing, and his staff for embracing this opportunity and throwing the full weight of their creative abilities into the color signature sheets. Your efforts to collect, organize, and collaborate with the editors truly brought this new addition to life. Steve also developed the cover design; his modern approach and artistic flair have translated the book's purpose into a beautiful, meaningful cover that will, hopefully, encourage readers to delve further.

Key to the success of this edition was the editors' ability to communicate quickly and easily with the contributors who were dispersed across the country. Facilitating this effort was Mike Ott, Raishad Peoples, Mike Friedenthal, and Wendy Stahl of the IT department, who made sure the book website, server, and ftp site were established, secure, and functional throughout. They also made sure that Lisa was able to "work on the go," allowing her to work with all the contributors effectively and efficiently.

Last but not least, I want to express my deep regard for our partner in this effort, Senior Editor Larry Hager of McGraw-Hill. He has guided us through this process three times now, each time just as supportive as the first. Thank you for believing in us, for helping us elevate land development consulting as a profession, and for making one of my dreams—this book—come true, again!

In 1956, if you had told me that our six-person land development consulting company would grow to become one of the top 50 A/E companies in the United States, I would have thought you were nuts! Along the way, I learned the hard way that real estate development is subject to the many ups and downs of the economy and could perhaps be characterized as the whipping boy of the business cycles. For that reason, we sought early on to diversify our company into other facets of the A/E business. This diversification effort has been hugely successful for us, but land development continues to be one of the primary underpinnings of our practice. We love it, and every new project receives the enthusiasm and professional care that we gave when we were first trying to establish ourselves in the industry. I urge the thousands of small land development consultants throughout the United States, however, to diversify into other facets of engineering to guard against the feast-or-famine nature of this business. After all, land development, as stated earlier, contains almost all facets of any specialty of civil engineering. Nevertheless, deep down we get supreme joy out of helping plan and build safe, healthy, financially feasible, sustainable, and beautiful places for people to live, work, worship, learn, shop, and play.

Sid Dewberry, PE, CLS
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PART I

OVERVIEW

Land development consulting merges the science of city building with the art of placemaking through a collaborative, multidisciplinary approach to project delivery. Encompassing the fields of planning, engineering, surveying, architecture, landscape architecture, construction, marketing, finance, and a host of other specialties, land development consulting is a dynamic profession that requires consultants to be technically skilled and creative. They must have their finger on the pulse of the community—the political climate, cultural and environmental priorities, infrastructure needs and desires—in order to reliably advise their clients, produce sound designs, and contribute to the development of high-quality places.

In order to fully appreciate the nuances of today's land development industry, it is important to understand its evolution. This first chapter examines the industry drivers—demographics, historic events, and economic, political, and social factors—that serve as the impetus for this growing branch of consulting. Also touched on in this chapter are the tenets of design—strength, function, and aesthetics—as well as brief introductions to the prevailing design philosophies including green or sustainable, neotraditional, and conventional. Last, and most important, this overview establishes a land development design process—clarified and detailed throughout the text—that can be used to navigate the increasingly complex maze of development regulations, required approvals, and permits.

This edition, like the second, presents the material in chronological order according to the typical land development process. While site design is a continuous process, it encompasses at least seven distinct steps (or stages), each with an associated deliverable documenting the migration through the design process.

STEP 1: *Feasibility/programming* initiates the process with a general review of the proposed program and existing site conditions, with particular emphasis on identification of environmental, cultural, and infrastructure resources.

STEP 2: *Site analysis* determines the allowable use of the site based on local master plans, codes, and ordinances and recommends a course of action to accomplish the development program with respect to those documents.

Feasibility review and site analysis are usually performed concurrently; these studies result in a complete site inventory, identify usable site area, and form the foundation of further design efforts through provision of adequate base mapping and establishment of project goals.

STEP 3: *Conceptual design* presents the initial organization of the development program.

STEP 4: *Schematic design* is a refinement of the initial concept sketches that adds scale, dimensions, and precise testing of specific uses, including building arrangements and infrastructure systems.

STEP 5: *Final design* is the conclusion to the primary design effort. Carried out predominantly by the engineers, preliminary plans are enhanced with a level of detail sufficient to construct all aspects of the project.

STEP 6: *Plan submission and permitting* represent the formal regulatory review of final design (construction) documents by all governing agencies as well as application for and procurement of all necessary site and building permits.

STEP 7: *Construction* is the final step in the land development process. During construction the land development consultant is a valuable resource for both the client and the contractor and is often responsible for stakeout, reviewing submittals, shop drawings, and RFIs, certain inspections, and field and formal revisions.

PART I

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CHAPTER 1

OVERVIEW OF THE LAND DEVELOPMENT PROCESS

Sidney O. Dewberry, PE, LS

INTRODUCTION

The conversion of land from one use to another is the generally accepted definition of land development. As used in this book, this definition is confined to land conversion associated with the modern communities that are being constructed, or reconstructed, for people to live, work, worship, shop, and play. This age-old process began when ancient societies organized themselves into tribes, settling on and claiming land, forming villages and primitive towns, for the mutual protection and livelihood of all. The great civilizations of Egypt, Greece, and Rome can be traced to humble beginnings of tribal communities. Their growth in size and complexity is typical of urban development and not unlike what we are experiencing today. With their complex roadways, aqueducts, commercial markets, and residential areas, the ancient problems associated with land development endeavors—those of adequate transportation, waste disposal, drainage, water supply, population densities, and others—posed a challenge then and continue to require innovative solutions today.

Today, the process for finding solutions and developing scenarios for land use that serve the greater good is a systematic one and is, to a large degree, uniform in principal and practice. The systematic approach to land use planning, analysis, and engineering is known as *land development design.* Carried out by highly educated and versatile urban design experts, land development design and consulting encompass a host of tasks including feasibility studies, zoning applications, environmental permits, and the hundreds of steps necessary to conceive, design, construct, and document a land development project.

The Conversion of Land

Since the early 1950s, the conversion of land to a different use generally meant a more intense use. The definition formerly applied almost exclusively to residential, commercial, retail, industrial, and office uses. It did not take long, however, before city planners and residents alike echoed Daniel Boone's call for elbow room and clamored to have areas preserved for recreational, educational, social, and cultural activities as well. In response to this societal need, the definition of land development was broadened to include such activities as converting rural land to agriculture use, constructing major transportation and utility systems, and even urban and suburban redevelopment projects. For the purposes of this handbook, land development is the conversion of land from one use to another, usually of greater intensity, and is typically applied to a single parcel or group of parcels (as opposed to a more linear infrastructure-only type of project) and includes supporting uses and infrastructure improvements.

Land development design and consulting constitute the systematic process of collecting data, studying and understanding the data, extrapolating the data, and creating on paper the plans for reshaping the land to yield a land development project that is politically, economically, and environmentally acceptable to the client and the public. Persuasion, salesmanship, and negotiation are all part of each step in the land development design process.

TABLE 1.1 Population of Principal Cities 1800–1850 (U.S. Census Bureau)

LOCATION	1800	1810	1820	1830	1840	1850
Boston, Mass.	24,937	33,250	43,298	61,392	93,383	136,881
New York, N.Y.	60,489	96,373	123,706	202,589	342,710	515,547
Philadelphia, Pa.	69,403	91,874	112,772	161,410	220,443	340,045
Baltimore, Md.	26,114	35,583	62,738	80,625	102,313	169,054
Washington, D.C.	3,210	8,208	13,217	18,827	23,354	40,001
Cincinnati, Oh.	750	2,540	9,642	24,831	46,338	115,436
New Orleans, La.	—	17,242	27,176	46,310	102,193	116,375

IN SEARCH OF "GREENER" PASTURES: A BACK-TO-THE-FUTURE LOOK AT THE LAND DEVELOPMENT INDUSTRY

Land Planning and Development in Historic Context

> At the heart of all suburban growth is land development—the conversion of rural or vacant land to some sort of residential use. The process involves property owners, speculators, banks, private lenders, builders, and buyers. As land values at the center of the metropolis rise, individual parcels either produce the higher yields to hold their place, or in the course of a few years, more profitable businesses move in on the site. By the same token, if much the same yield can be earned at a peripheral site of lower value, there is little incentive to remain in and around the central business district. The pattern of urban land investments affects the value of outlying farmlands, which either increase yields by more profitable crop, or, as is the usually the case, they give way to more lucrative subdivision and real-estate developments. (Jackson, 1985)[1]

These words describe the fundamental interrelationship of real estate, suburbanization, and land development that spurred the growth of suburban America largely between 1930 and 2000. Land development, by nature, ties together a wide range of interests, pressures, user groups, and economic interests; thus, it is a design field that is heavily influenced by the surrounding context—political, economic, environmental, and cultural—within which the land development will take place. This contextual influence has driven the development of laws that provide a common framework for land planning and design and has directed the focus of land development efforts throughout U.S. history.

Roots of Modern Zoning Practices. In the late 1800s and early 1900s, both in Europe and in America, the Industrial Revolution, overall population growth, and more prevalent work opportunities drew citizens to cities (see Table 1.1). High-rise residential structures and factories were built, and the modern city was born. The new high-density uses led to conflicts between industrial and residential uses and to concerns over the health of citizens living in substandard conditions in city tenements, where transmission of disease and spread of fires could be rapid and deadly. These concerns led to legislation governing land use that changed the parameters for land planning and development in this country forever.

New York City adopted the nation's first comprehensive zoning ordinance in 1916 as the combined result of the growing density in the downtown core and increasing political pressure to distinguish residential zones from the garment district's ever more widespread industrial and commercial properties (Nolon and Salkin, 2006, pp. 67–68). The concept of the government having the power to divide land and to assign appropriate land uses has dominated land-planning practice since that time.

Countless legal cases have subsequently challenged and further defined the power of the government over that of property owners, with the idea in mind of restricting nuisances to other property owners and protecting citizens from the adverse effects of undesirable land uses. The "police power" of the state to make decisions in the public's best interest regarding land use forms the basis of eminent domain—a defining feature in the relationship between landowners and government in this country.

Outside of the structure established by land use law, the economic, social, and cultural context surrounding the land-planning process has defined the focus and direction of land development initiatives throughout American history. Transportation is one factor that has long influenced land growth patterns, through its pervasive effect on American lifestyles.

The Role of "Modern" Transportation. In the 1700s, homes, shops, public buildings, hotels, and places of worship and commerce coexisted within centers of trade to form the urban core (town center, central business district, etc.).

[1]A comprehensive treatise on suburban growth in the United States is Kenneth T. Jackson's *Crabgrass Frontier: The Suburbanization of the United States.*

Figure 1.1 An antique omnibus. (Chicago Historical Society)

This pattern of land use reflects a lifestyle whose primary mode of transportation was by horse or on foot, with shopkeepers typically living above their stores or within one mile of the town center. The areas close to the town center were the most desirable areas for development, a concept reflected by property values and the level of resident investment.

During the early 1800s, new modes of mass transit began to develop. Omnibus mass transit, first used in France in 1828, was established in New York in 1832 (see Figure 1.1); Philadelphia's system followed two years later. Boston had established a system by 1835, and Baltimore's began in 1844. The horse-drawn omnibus was superseded by the fixed rail horse-drawn trolleys and horsecar (Figure 1.2), and eventually replaced by the electric streetcar (Figure 1.3). In cities divided by rivers, steam ferries came into use, and commuter railroads were used for longer-distance commutes and for travel between cities. The radical change in distances traveled enabled city boundaries to increase beyond what could be traversed on foot or horseback and permitted residences farther from the urban core.

Ford's invention of the assembly line in 1914 reduced the price of the Model T from $950 in 1910 to $290 in 1924. Automobile registrations increased from 1 million in 1913 to 26 million by 1927. Because people no longer had to wait or walk to rail transportation, suburban developments were freed from the limitations of the rail lines, thus further expanding the urban fringe.

Cultural Shift: The American Dream Moves from the City to the Suburb. With an expanded population and broader transportation network, the focus on land planning shifted as the profile of the city changed from that of a "walking city" to that of a "commuter city." As the outer fringe areas became increasingly accessible, they ceased to be perceived as the residence for the lower ranks and developed instead into a highly desired area of residence for higher-income families seeking to distance themselves from the inner city's unattractive squalor.[2] Table 1.1 shows the changing population of principal cities from 1800 to 1850 during the initial development of residential areas outside cities. During this time the focus of land development shifted and specialized, with industrial and commercial development centering in downtown areas. Residential development became increasingly

[2]Today, in the early part of the twenty-first century, the outer fringes of a metropolitan city are typically 20 miles or more from the inner city. In the early nineteenth century, the outer fringes were only 1 to 2 miles from the city's core or central business district.

FIGURE 1.2 Horsecar of the nineteenth century. (Chicago Historical Society)

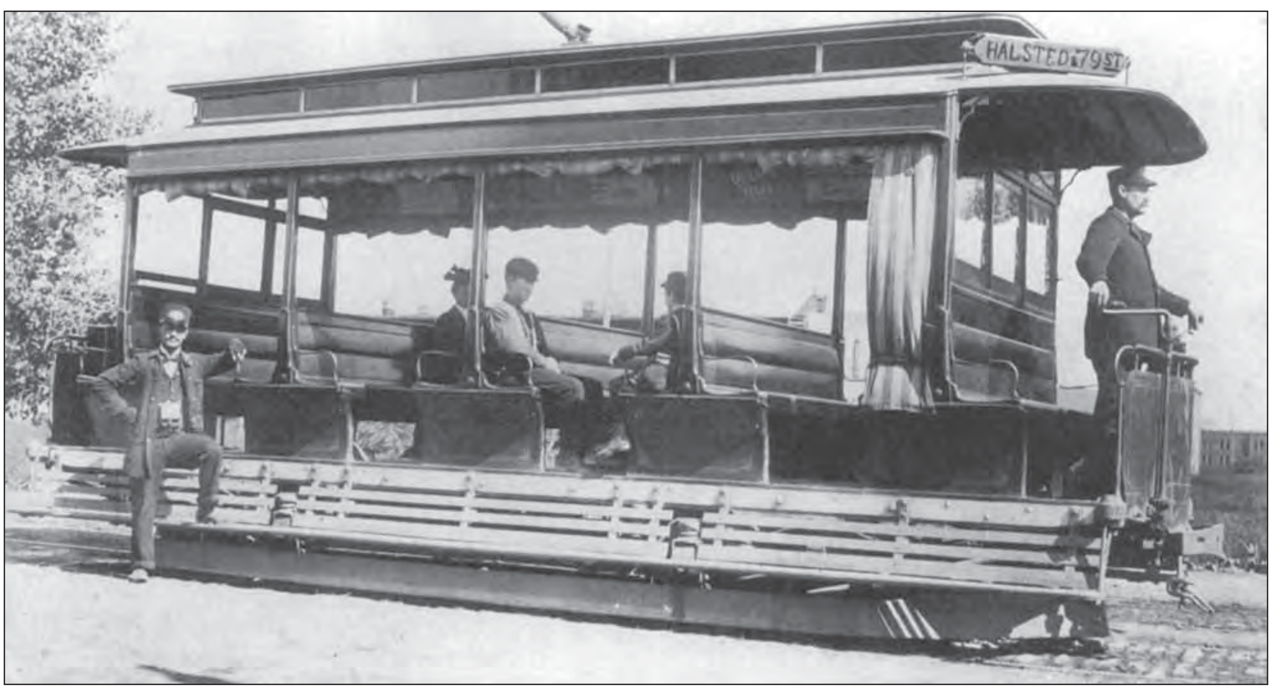

FIGURE 1.3 Typical electric streetcar. (Chicago Historical Society)

focused on neighborhood planning and development in the growing suburban fringe.

Throughout American history, local politics have also played an integral role in land planning and development. As transportation improvements opened new areas for growth in the 1800s and early 1900s, many would-be homeowners and real estate specialists became active in the city building process, lobbying city governments to extend the infrastructure, pressuring streetcar companies to build tracks to suburban areas. With municipalities involved in paying for infrastructure, setting land boundaries, governing land uses through zoning, and mitigating conflicts among landowners, land development and the public process became inextricably linked in ways still felt today. With improved roads, new home construction with modernized electrical utilities, and sanitary sewer systems, increased demand was rapid and rewarding. Developers and builders rushed to take advantage of new suburban housing market opportunities.

Success—Suburban Style and Aesthetics. Aesthetics became increasingly important to land planning during the nineteenth century. The preference for life away from the center city was characteristic of the middle class of the latter part of the nineteenth century. The suburban single-family dwelling was viewed by many families as a sign of success and the reward for hard work. The new attitude toward suburban living and the availability of relatively inexpensive housing had an impact on the architectural style of houses as well. Instead of citylike row houses with relatively small yards or the rural farm-type setting with large vegetable-herb gardens, moderately sized yards with meticulously manicured lawns, shade trees, and picturesque flower beds became the norm.

The layout of neighborhoods initially contained logistical features that facilitated land planning. Early suburban developments reflected the gridiron street patterns of most cities. The system was simple, maximized the number of lots, and was easy to survey. However, new progressive philosophies evolved in the late nineteenth century that combined the desire for aesthetically appealing neighborhoods with the idea of preserving natural beauty.

The Beginnings of Modern Land Development Design. One of the first planned picturesque communities to capitalize on the new trend in aesthetic neighborhood design was the brainchild of Llewellyn S. Haskell and Alexander Jackson Davis in 1857. Haskell owned 400 acres in the eastern foothills of New Jersey and employed Davis to prepare the site plan for a development called Llewellyn Park. Davis's layout included two heretofore unheard-of features: curvilinear streets and 59 acres of natural open space. Both features took full advantage of the natural landscape. Additional open space was provided by the average lot size of 3 acres. Property owners were able to freely landscape their lawns but were encouraged to harmonize their property with the character of the land.

Frederick Law Olmsted was another advocate of maintaining the natural character of land. He employed this technique in his first development, Riverside, a 1600-acre site located outside of Chicago, developed in 1868. Together with his partner Calvert Vaux, they molded the development into their conception of a well-planned proper residential district. Riverside included curvilinear streets, generous 100-foot by 225-foot lots, and such amenities as a lake and a total of 700 acres for parks and recreation, of which one was a 160-acre park along the Des Plaines River. Houses were set back 30 feet from the street, and homeowners were required to maintain immaculate gardens.

Haskell, Davis, and Olmsted, like their successors at the turn of the twentieth century, were not unlike the land developers of recent times. Rarely did a single individual (or firm) buy land, generate the site plan, construct the infrastructure and houses, and then finance sales to the ultimate owners. Typically an engineer or surveyor was hired to design the site. The finished lots were then sold, usually at auction, to buyers who would build the houses for sale or for their own occupancy, or hold the finished lots as speculation/investment. (See Figure 1.4.)

The End of the First Boom and the Beginning of Federal Financing Assistance. The stock market crash of October 1929 ended the housing boom of the 1920s. Between 1928 and 1933 construction of residential property decreased by

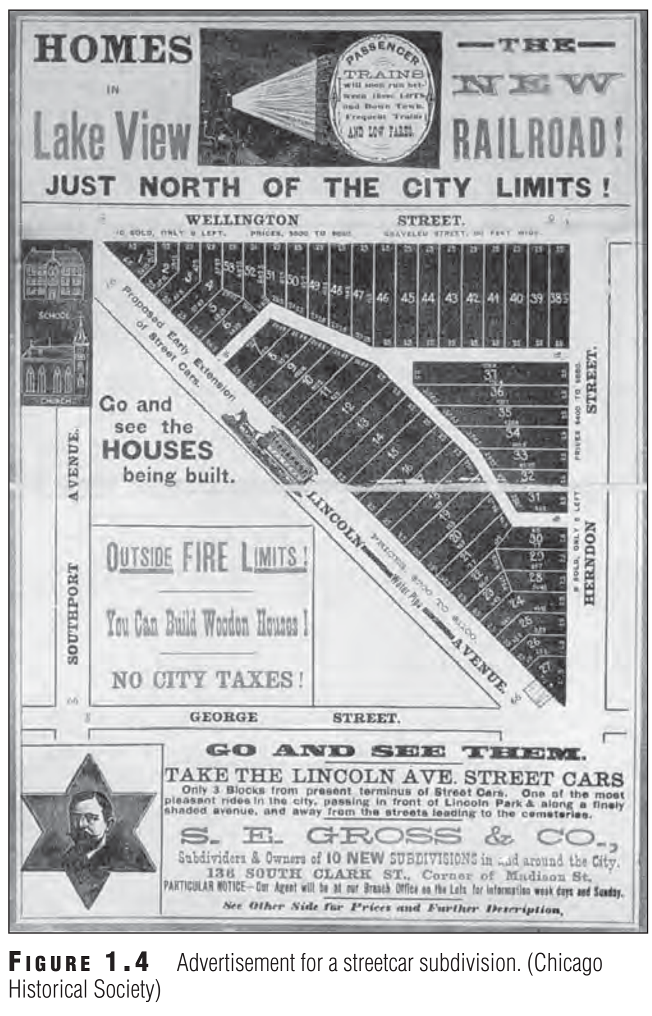

FIGURE 1.4 Advertisement for a streetcar subdivision. (Chicago Historical Society)

95 percent. The collapse in the housing industry prompted action by Congress. The Emergency Farm Mortgage Act of 1933 was intended to reduce rural foreclosure. The Home Owners' Loan Corporation (HOLC) provided low-interest loans for owners to recover homes lost through forced sale. In the 1920s the typical length of a mortgage was 5 to 10 years. The HOLC program increased the repayment period to 20 years.

Another significant action by Congress was the National Housing Act of 1934, which created the Federal Housing Administration (FHA). An FHA-secured loan required only a 10 percent down payment, roughly a third of what savings and loan associations required. The repayment period for the guaranteed mortgages increased to 25 or 30 years, with loans fully amortized. Additionally, the FHA set minimum construction standards for houses that were mortgaged under the program. The positive effect of the creation of the FHA was evidenced by 332,000 new housing starts in 1937. By 1941 housing starts were up to 619,000.

Federal Mortgage Guarantees and Industry Recovery. World War II had a significant impact on the financing of houses, forcing another slowdown in residential construction. Housing starts declined to 139,000 in 1944. After the war, marriages and birthrates increased dramatically, creating a high demand for affordable housing. The Servicemen's Readjustment Act of 1944 created a Veterans Administration mortgage program similar to that of the FHA. The assurance of federal mortgage guarantees resulted in housing starts skyrocketing to 1,015,000 in 1946. By 1949, housing starts had reached an all-time high of 1,430,000.

To meet this demand for housing, designers developed innovative mass production techniques. The development of Levittown on Long Island transformed 4000 acres of potato farm into 17,400 dwellings. This massive undertaking—the biggest private housing project in the United States—began in 1946. The Levitt family did for the housing industry what Henry Ford had done for the automobile industry three decades earlier.

Back to the Future: Where Do We Go from Here?

The land development industry is the direct result of the ongoing need for housing and services as communities expand their borders and the population pursues the American Dream. Suburbanization in the nineteenth and early part of the twentieth century evolved as a result of a combination of factors such as increased population, the need for affordable housing, and the innate American desire to own one's own castle rather than rent. Science and technology in the form of new types of transportation, building materials, and innovative construction methods lowered the cost of housing. Together with innovative financing programs, these advancements helped more and more middle-class Americans achieve that dream.

The challenge for land development professionals is to understand the factors contributing to the demand for growth and expansion and to be able to remain flexible enough to respond to the changing needs of the market. Part of that understanding includes knowing where the industry has been and how it evolved into the practices and procedures of today. The other part is understanding the nature of the land development industry and how to maintain the standards of quality, flexibility, and value that we have attained. Design professionals must meet the challenges of today while not losing sight of yesterday's lessons and today's high standards.

> It used to be that a home builder depended largely on a surveyor to lay out the lots, and the local city or town to extend utilities and streets into the subdivision. That is no longer the case.
>
> Following World War II and the Korean War, there has been a continuous and large demand for housing, caused by retiring veterans, rapid migration to our cities, smaller families and changing life-styles. This demand has required a revolutionary approach to the financing of all facilities connected with housing. With government leadership and subsidies, huge mortgages with minimum down payments have been made available to Americans of all income levels. The large amount of capital generated by this process has revolutionized home construction and ownership in America in the past 30 years. Other major public works programs, such as the interstate highway system, mass transit, pollution control, and clean water acts, are all small in comparison to the billions which go into housing every year. While the social changes of these public works programs are vast and historical, home building and related construction has been the largest single industry in the United States for at least three decades. (Dewberry, 1979)

Building for Today's Demographic

The global population is predicted to be over 9 billion people in 2050; this represents an increase of 2.8 billion people worldwide, over 100 million in the United States alone.[3] Designing and building the homes, workplaces, and playgrounds to accommodate this increasingly diverse population is a tall task, even for a community of seasoned land development professionals.

The Modern-Day Consumer. In addition to the growing population, changing demographics (baby boomers are retiring, Gen Y is coming of age, and immigrants are establishing roots[4]) and an enhanced environmental consciousness are resulting in noteworthy changes to the land development process in terms of programming and implementation strategies. Meeting the demands of the demographic forecasts means increased development and redevelopment in rural, suburban, and urban areas; however, the means and methods by which we design and build

[3]U.S. Census Bureau, International Data Base. Total Midyear Population for the World: 1950–2050, updated July 2007.

[4]Handley, John. 2005. Three Big Forces Poised to Change the Market. *Baltimore Sun,* January 9; reprinted by ULI (online).

must continually evolve in order to create more self-sufficient, sustainable sites that are in tune with the culture and environment of the specific place and projected users.

Faced with these market transitions, the land development professional is confronted with a host of new challenges ranging from rebuilding aging infrastructure to land availability constraints, from growth controls to forced redevelopment of degraded sites, from the desire for rural living to the market demand for 24-hour access to amenities such as the Internet and basic community services. In addition to the physical challenges of site development, the social climate surrounding land development has never been so fiery. Informed, active community members and politicians are more closely linked to the development process and are effectively forcing development professionals to think creatively, implement innovative technologies, and provide facilities that go beyond the framework of traditional, in many cases, outdated regulations.

Twenty-First-Century Climate Change. Modern-day consumers are making these new lifestyle choices based in part on age and cultural factors but also in response to the twenty-first-century social and political climate. Cities are reemerging; in fact, the United Nations predicts that the urban population will exceed the rural population for the first time ever in 2010.[5] The definition of *green* is changing—being green, for many, no longer means a perfectly manicured yard and pruned garden but an energy-efficient home, a rooftop garden, or a nearby park. This is a time of tech-savvy consumers in which everyone has access to the current body of knowledge on the environment, global warming, and the consequences of the events of 9/11 and the subsequent war on terrorism. Concerns about safety and security, the price of gasoline, and the consequences of lifestyle choices are pervasive and significantly influence home-buying preferences. New considerations such as commuting preferences, life-work balance, work-from-home options, energy usage, and food production all influence consumer behavior and the lifestyle choices that are beginning to drive the land development industry. Land development today is about community, placemaking, and building better on each project in all locations, for the improvement not only of the greater community but of the individual within that community.

THE LAND DEVELOPMENT PROCESS

This book is, in its entirety, an overview of the land design process as it applies to engineering, planning, and surveying. The engineer, planner, and surveyor are an integral part of the development team. They are usually among the first to arrive on the site and the last to leave after completion. They help guide and direct the process from start to finish. As an aid in understanding the overall land design process, consider a hypothetical project.

Imagine there is a developer or owner who wishes to construct and sell some residential houses in a certain price range in a certain region. He or she may initially contact a real estate broker to describe the proposed project and ask the broker to find a suitable piece of land. More likely, a real estate broker will contact the developer and offer a certain piece of land that will support the style, amenities, and overall goals of the particular project. The first thing the developer will do, if not already familiar with the neighborhood, is visit the site and become familiar with the piece of land. On first inspection, does it appeal to the eye and appear worth pursuing? Is the proposed sale price comparable to that of other properties in the existing neighborhood? Are there environmental constraints or opportunities? Are utilities available? What is the zoning? These are the first of many preliminary questions.

If the initial inspection proves promising, an experienced developer then usually performs a brief analysis of the property, which addresses essential items, and then proceeds immediately to get the property under contract. Land, especially well-located land, is at a premium; thus, speed is often critical to prevent a competitor from gaining control of promising property. To act quickly but still minimize risk, many developers will initiate an *option* on the property, thus making the final purchase contingent on satisfactory resolution of pertinent land design issues such as the ability to overcome any environmental issues or achieve successful rezoning. The next step in resolving these issues is to employ a land development consulting team to support a more detailed feasibility, site analysis, and programming effort.

During the feasibility period, the developer performs a complete analysis for the property likely including a market survey, financing options, sales potential, pro forma financial models of the proposed project, and, not the least, a detailed engineering feasibility study. The detailed engineering feasibility study and site analysis should address such critical questions as these: Are there environmental or cultural resources present on-site that warrant preservation? Do sufficient roads and utilities exist to service the development program? What is the zoning status? Can the developer reasonably expect to successfully rezone? How many lots or what square footage will the project yield? What is the cost of providing the needed infrastructure to the site, both on-site and off-site? What is the history of support or opposition to similar projects by citizens/neighbors and politicians in this area?

If the engineer is familiar with the general area and jurisdictional requirements, and is able to sufficiently answer the pertinent questions, the developer may be able to proceed with negotiations to purchase the property (exercise the option) within a relatively short period of time. If a more detailed study is required, there is still usually a limited number of days—typically 15 to 45, although it could take

[5]Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, *World Population Prospects: The 2006 Revision and World Urbanization Prospects: The 2005 Revision,* http://esa.un.org/unpp, December 11, 2007.

60 days or more, during which time the purchaser can release the option to purchase the property for any number of reasons. If the feasibility study or other analysis indicate the potential for problems, renegotiations may be necessary. Oftentimes during a feasibility study period, issues arise that cause the developer to drop the contract or renegotiate the terms based on the new information.

The next step in the process usually involves hiring a surveyor to do a boundary and topographic survey. The boundary survey is required to transfer title, while the topographic survey is required to accomplish further design efforts.

The planner (whether the surveyor, engineer, architect, or landscape architect) will then develop a concept design of the proposed project working closely with the developer and all members of the team.

If rezoning is involved, the developer must mobilize the entire team and develop a winning strategy. Chapter 9 in this book touches on rezoning in detail.

Once rezoning has been achieved, the next step is preparation of a detailed preliminary plan or schematic drawing. The concept developed earlier or during the rezoning process provides the basis for this plan, with more details including tentative road sections, utility layouts, and easement locations. Other details to be addressed include how storm runoff is to be handled, what erosion and sedimentation controls are anticipated, and how access, turning lanes, right-turn lanes, building setbacks, lot sizes, tree preservation, and the treatment of soils will be handled. All of these issues, and more, are related to the preparation of the final plans and should be addressed in the detailed preliminary plans.

The preliminary plans must then be processed through all the relevant agencies. In most cases, revisions are required before approval is granted. These requested revisions can be mandatory but more often are negotiable. Skilled consultants can sometimes make a big difference by successfully managing revisions before the project reaches final design. It is recommended that this preliminary plan be presented to affected citizens even though they may have been involved in the rezoning. This inclusionary process aids in gaining community support and should be completed prior to embarking on final design.

Once all required approvals of the preliminary plan have been obtained, preparation of detailed construction plans can proceed. There may be several plans—typically, public improvements versus private improvements—or all may be included on one comprehensive set of drawings. Water and/or sewer systems must often be engineered separately and reviewed and approved by that particular agency or authority. This same procedure will likely occur during the design of the streets, drainage, and conduit.

Concurrent with the engineer's preparing of these final plans, the architect may prepare detailed architectural plans for review and approval by the agencies. Once all final plans have been approved, the developer must post a bond guaranteeing the work will be completed in accordance with the approved plans. The engineer usually assists the developer in preparing cost estimates for budgeting and bonding purposes. Frequently, the developer will engage the engineer to oversee selection of a contractor or contractors to perform the construction. This selection process may be through a closed-bid process or a negotiated sole-source procurement.

The next step is construction. The surveyor is involved in giving lines and grades to the contractor to make sure that the completed project complies with the intent of the final construction drawings. Sometimes the engineer will provide his or her own on-site inspections to ensure that specifications are fully honored, although this is a duplication of effort in most jurisdictions, since the developer must pay a permit fee that covers the cost of inspections by the jurisdiction's own inspectors.

Shortly after construction commences (sometimes even before), the developer will launch a marketing campaign. In residential development scenarios, model homes are often used to show potential buyers the types of floor plans and upgrades that will be available within the community. Early construction of models may require careful construction phasing on the part of the engineer and contractor in order to facilitate early access to and use of the models. In some cases, floor plans and rendered drawings, typically supplied by the architect or engineer/planner, may be the only sales tool. Developers typically try to keep sales on pace with construction. The pace of the project is an important point of communication among the developer, engineer, and contractor, as phasing of a larger project is critical in terms of balancing financing/funding with construction and sales.

The final step, after the infrastructure is installed and the streets are paved, is to conduct an *as-built survey* and set final property corners. Final inspections and the engineer's certification are the last official actions in the process and should allow for bond release and occupancy permits.

This overview of the land design process has been simplified for ease of communication. It is meant to be an overview. The details of each step in the process and the specific technical aspects can be found in subsequent chapters of this book.

Communication Skills

Overlooked and underemphasized in land development are good communication skills. The process requires members of the team to be in constant communication with each other, with approval agencies, and with citizens. A project undergoes many changes between its inception and completion. These changes occur very rapidly and for many reasons. It is imperative to communicate changes and updates to the proper people at the proper time. To do this effectively, one must ultimately know what has transpired technically as well as who should know which facts and what actions should follow. The ability to effectively communicate through letter writing, report writing, and technical writing is a very important credential for the land development professional. Especially in today's world of e-mail, text messaging, cell phones, and personal digital assistants (PDAs), the ability to connect instantaneously and conveniently should not mitigate the art of insightful, meaningful correspondence. Further, documentation of project-related correspondence is critical from a business standpoint. While consultants should absolutely take advantage of the tools available, they should also maintain a prudent plan for tracking, saving, and retrieving all forms of project correspondence.

Equally important is the ability to present ideas clearly and precisely. Good public speaking skills before small and large groups is important in many professions, but it is particularly important in land development, where presentations to public approval agencies often make or break a project. This includes skills in adapting material for a technical audience, a nontechnical group, or a mixture of the two. Accuracy should be indisputable, and enthusiasm is a key ingredient. As always, respect for the time available is essential. Where appropriate, the use of humor can go a long way in easing tensions and building the relationships necessary to ensure the project receives a fair hearing. The ability to communicate effectively, regardless of the media, is the mark of a leader and an essential quality for today's land development professional.

Public Involvement

In today's land development practice, a working knowledge of the public process is essential for success. Public agencies should be treated as part of the design team. Even though the relationship may seem mostly regulatory, in many jurisdictions, public entities have the power to shape projects, deny applications, and grant approvals. Smart designers establish early rapport with all agencies from which they will require later approval. The best way to establish this rapport is to thoroughly understand their regulations and submit compliant plans that are clear, easy to read, and complete. Resist the urge to avoid compliance to reduce costs or save time. This approach will only result in delays and lost time and money, as well as loss of credibility with the agencies in question. If there is a disagreement with the regulation for a valid reason, or if the regulation simply does not apply to the specific development conditions, waivers or variances can often be obtained by confronting the issue squarely and working with the approval agencies to obtain a solution.

Involvement by public agencies is pervasive and must be understood thoroughly by the land designers, as there are many agencies involved, often with conflicting goals. Approvals must be obtained from all involved agencies before the project can proceed. Compliance with applicable rules and regulations is often required by ordinances or local, state, or federal law. Brief descriptions of representative agencies and selected rules are included throughout this book.

The nature of public agency involvement varies greatly from jurisdiction to jurisdiction and agency to agency. Federal regulations, however, are reasonably consistent. Each state has its own set of rules that are dissimilar to those of other states. Even within a state, regulations in individual counties, towns, and cities can be different. Areas that are more urban and suburban in nature generally have a more detailed set of regulations than rural areas, although this is changing rapidly. Sometimes regional authorities have jurisdiction for such services as sewer or water. It is imperative that land designers thoroughly understand the rules of all the agencies having jurisdiction over a project.

The length of time involved in actual planning, engineering, and surveying is short compared to the length of time required to gain all the necessary approvals. Many politicians have been elected on platforms pledging to cut and streamline regulations—not only for private projects but also for public projects such as highways and utilities. Regardless of these good intentions, the regulatory process continues to expand as new regulations and agencies that enforce them continue to be created.

Citizens have become much more involved in the process of approvals for a project. Citizens can be very skillful in opposing projects they don't want. They often have experts of their own, skilled in the complexity of land designs and versed in the myriad of regulations a developer must handle in order to gain final approval. These regulations are open to interpretation, and it is very common for petitions to be made to the courts for final resolutions.

It is important to establish early relationships with citizens who may be interested in the development of a particular piece of land. Early participation by these citizens can usually lead to modifications in a plan that will be acceptable to both the citizens and the developer. It is not always what you do *but how you do it* that is important to affected neighbors. Many things can be offered or included in a development plan to make it palatable to citizens or neighbors. The communication, design, and negotiation process that takes place with the immediate community has expanded notably in recent years, as citizens have become more intimately aware of the possibilities and consequences inherent to land development.

Basis for Design

Quality design is a much used and many times misused phrase. In today's world, quality design is much more than the ability to ". . . determine precisely how best to develop our program on the site selected, in specific forms and materials . . ." (Eckbo, 1969). Quality design is a result of the design team's ability to produce a plan that not only conforms to the client's established development program, goals and objectives, recognized site constraints, laws, ordinances, regulations/policies, accepted design standards, and market considerations, but also has withstood the test of private and public special-interest groups' scrutiny.

At the risk of oversimplification, the prerequisites for undertaking quality site design are predicated on a designer's level of familiarity and dexterity in dealing with a core of base information that is required throughout the process. The information base may be loosely categorized under the following major topics: development program, site, planning and regulatory controls, and design team.

Development Program. The development program is initially a determination on the part of the client/owner regarding what type of development is expected for a given parcel of land. For the most part, such preliminary determinations are based on a cursory review of zoning, planning, and market considerations as applied to a specific property. This development program concept is presented to the project design team for discussion and refinement. The challenge of project design is formulating a response that simultaneously balances the highest and best land use with the character of the site and its environs, client and consumer expectations, economic and marketing factors, and public/private approval requirements.

Land uses and their associated building types need to be consistent with current construction practices and consumer and user requirements. Market conditions, development costs, and numerous alternatives in development technologies afford the designer the opportunity to develop distinctly different designs for any given property. Design should be predicated upon a thorough understanding and appreciation of the success associated with previous land development designs. Such awareness strengthens the position of the land development designer. The intent is not to mimic what has proven successful, but rather to gain an understanding of the reasons for success and expand on those attributes. The fundamental requirement of land design rests in a working knowledge of the physical/functional characteristics and constraints associated with specific building products. While certain base considerations, such as adequate vehicular access, represent a common requirement for all land use types, the appropriate design response varies substantially as one proceeds from detailing low-density single-family residences to the more complex urban mixed-use development.

The Site. The site, or particular piece of real estate on which a development program will be implemented, affords a special set of resources and opportunities for project design. Each site is unique and requires an understanding of and appreciation for the specific characteristics to elicit a tailored design response. Consideration should be inclusive of both surface and subsurface characteristics, as well as the dynamics associated with the natural and cultural context that prescribe its unique character. Attributes of a site that are normally considered relevant to land development activity include those that bear on the land's ability to absorb specific development program elements. These include both on-site and off-site considerations and entail a range of issues from site configuration to adjacent land uses.

Regulatory Controls. Knowledge of the public regulatory controls, design standards, and technical requirements, as well as preexisting legal requirements or development conditions associated with development of a given property, is necessary for successful project design. Site design cannot commence without a thorough knowledge of the appropriate regulatory ground rules. Issues relating to local comprehensive plans, zoning and subdivision ordinances, and other regulatory controls are first analyzed during the feasibility and programming stage of the design process and remain an influence until final site plan approval.

Beyond the local land use laws, there may be other regulations and legal requirements that have varying degrees of impact on site design. Restrictive covenants that have been placed on a given property may dictate a site design with standards more stringent than state or local jurisdictions. Existing planned developments may mandate the designer to work within previously established design guidelines. Further, special development conditions may have been agreed to or imposed upon the land at a previous time in the development review and approval process. Such conditions may direct or influence design of a particular site in a manner atypical of other sites with similar uses.

Finally, statutes and policies of the local, state, and federal governments provide further regulation of such items as wetlands, coastal zones, hazardous waste, air and water quality, noise, and handicapped accessibility. These considerations, coupled with varying building code requirements relative to building access and spacing, can significantly influence site design and engineering.

It is imperative that the designer bring as much information to the design effort as possible. All appropriate rules and regulations that may affect the design aspects of a specific project must be understood at the outset of the design process. While manipulation of select site characteristics and development program components may allow a degree of interpretation and flexibility, noncompliance with statutory and/or legal requirements is rarely tolerated. The ultimate test of a successful design effort is whether or not it can be approved and constructed.

Design Team. Who are these experts following in the footsteps of Haskell, Davis, and Olmsted? Oftentimes the key land development consultant is the civil engineer and/or land surveyor. This is especially true for smaller projects and in less urbanized areas. Originally, the engineer and/or surveyor completed all relevant land development services. Today, however, the story is a bit different. The acceleration of urbanization in the United States, along with an increasingly complex and regulated planning and design process wherein citizens are deeply involved, has resulted in many experts—*specialists*—becoming involved in the process and on the design team.

In a typical project, the land development team could consist of any of the following:

- *Client:* While the land development client may be the end developer or builder, it is not unusual for the designer to operate under the general direction of a representative of a major corporate, institutional, or financial interest. To establish a successful working relationship, a designer must understand the client's familiarity and past experience in land development and project design. The client's degree of familiarity with project design, the local land development climate, and the approval process may have significant bearing on the latitude extended to their design consultants. It is prudent to confirm the services that are expected from the design consultant at the beginning of the process to minimize unrealistic expectations. Frequently, several individuals within an organization may represent the client; in this case, it is important to establish an appreciation of each member's role and responsibilities, particularly in terms of who will ultimately make project design decisions.

■ *Market analyst/researcher:* Market analysts often provide varying levels of feasibility studies that assist in the formulation of project-specific building programs. In this regard, their role in project design can range from determining and describing the details of the development program to providing guidance on locating uses on the site. The importance of this discipline varies with the proposed use or development program and the client's ability to perform the necessary studies independently. A market study may be required to obtain development financing in addition to providing the client/designer with advice relating to the established development program.

■ *Attorney/legal counsel:* The complexity of regulatory controls and public administrative procedures has prompted an increase in the participation of legal counsel in the land development process. While primarily responsible for the preparation and review of documents associated with legal or procedural requirements, they may also have a potentially significant role in project design. First, by virtue of their prior exposure to a variety of design efforts, they may have knowledge of comparable, successful projects. Second, depending on their personal relationship with the client, they may be positioned to influence decision making during the project design process.

■ *Urban planners:* Given the increased complexity of local zoning and planning documents, the urban planner's role in the design process has increased notably. Based on knowledge of the local zoning/planning requirements, the urban planner is in a position to guide the design team by interpreting the impact of governmental regulatory requirements on the design process. Often, the urban planner will team up with the project attorney to act as a front-end team to carry the design documents through the public review process. Due to their involvement in local planning and zoning initiatives, the urban planner is often able to cultivate a positive relationship with administrative staff and elected officials. This relationship is important to the design team as the urban planner gains access to staff and elected officials to promote project advocacy.

■ *Transportation planners:* Concern with the impact of new development on the existing vehicular transportation networks has made transportation planners integral members of the design team in many communities. This inclusion has been prompted by requirements that proposed development activity be subjected to a rigorous assessment of projected traffic impacts and documentation of associated roadway improvements necessary to sustain acceptable levels of service. The nature and extent of required on- and off-site road improvements varies with the size and specifics of each project. There is significant financial and design coordination associated with such infrastructure improvements that may have direct bearing on an appropriate design response.

■ *Project designer:* Generally, the principal site designer/planner has been schooled in the physical design aspects of land planning with education and/or training in landscape architecture, architecture, urban design, civil engineering, planning, or a related discipline. While the project designer is responsible for the actual preparation of a design response, the design process is generally carried out in close cooperation with other members of the design team. The core design team may be comprised of professionals from a single firm offering multidiscipline services or representatives of different firms providing specialty design or engineering consultation. In addition to having knowledge of the physical design aspects, the designer must also understand and be responsive to the client's preferences in accomplishing the established development program, even at times when the client's program is more of a seat-of-the-pants reaction than a reflection of sound planning, zoning, and design principals. It is, in part, the designer's role to tactfully respond to the initial proposed development program with a plan that conforms to planning and zoning regulations, is a marketable design, and meets the client's requirements.

■ *Civil engineers:* Civil engineers have a very important technical role in the project design and site-planning process. In the early stages of design, civil engineers provide valuable information in terms of the location, routing, and sizing of various site infrastructure features including street improvements, stormwater management facilities, sanitary sewerage, water systems, and other utilities. The engineer's involvement in the early design stages is important because technical decisions will be carried through to final site plan design and ultimately certified by a licensed professional engineer. Given their typical responsibility in the preparation of the final site plans and construction documents, their early participation in the design process is essential.

■ *Environmental specialists:* Some level of environmental assessment is usually required as part of land development activity. Historians, archaeologists, botanists, acoustical specialists, arborists, geologists, hydrologists, and other environmental scientists have increasingly become participants in the design and development process. Their participation may occur throughout the design process, commencing at preliminary site investigation and extending through to final design, with the formulation of measures to mitigate the impacts of development. The role of environmental scientists varies from project to project. However, given the increased emphasis on protecting the environment by preservation, conservation, buffering, and other mitigation measures, their role is important.

- *Surveyors:* Prior to about 1950, the surveyor was the key player in laying out a new subdivision. Suburban construction, still largely rural and new development pushed out from the fringes of the urban core, was usually a matter of laying out lots, cutting in the streets, and installing roadside ditches and some cross-draining culverts. As development intensified and new regulations for improved infrastructure were promulgated, surveyors began to become civil engineers or added civil engineers to their staff. The basic services of the land surveyor are still very important to the overall success of the project. It is the surveyor who provides the boundary survey and topographic information that the designers must have in order to begin. Not only is the exact computation for street and lot alignment the job of the surveyor, but also the final horizontal and vertical alignment of all the infrastructure and buildings to ensure that the wishes of the designer and civil engineer are complied with. It has often been said that surveyors are the first and the last people on the job—they set the final permanent monumentation and complete as-builts to establish a permanent record of improvements.

- *Public review/approval agents/citizens:* Representatives of the public interest have a significant role in project design. While jurisdictional regulations establish the ground rules, public agency review and interpretation of public policy and performance criteria, as well as citizen concerns, have a significant influence on many aspects of project design. Citizens are ultimately the users of a particular project, so their input is both necessary and helpful, as they can give developers early indication of critical issues and priorities.

Others who play various roles, depending on the project, include the financial institution, real estate brokers and specialists, landscape architects, geotechnical engineers/geologists, structural engineers, archaeologists, sociologists, recreational specialists, cultural and education specialists, sustainable design consultants or Leadership in Energy and Environmental Design Accredited Professionals (LEED APs), and, of course, architects. For the purposes of this handbook, architectural design is included only insofar as it provides preliminary or schematic elements sufficient to define size, bulk, shape, and densities. Appearance, heights, setbacks, and aesthetics factor into the final product and for this reason architects are frequently members of land development design teams.

Land development has become a very complex industry, and the design team requires a comprehensive understanding of this industry. Persons involved in this undertaking have had to become specialists; however, the best consultants maintain a broad knowledge of the popular terms and principles used in the industry and strive to develop an overall knowledge of all facets of the process. (See Figure 1.5.)

Traditional Steps in the Land Development Design Process

Land development design has traditionally been composed of several distinct steps or stages leading to the final plan. While structured to be orderly and sequential, few problem-solving endeavors follow a straight-line path to solution. The land development project design process is no exception. The process requires sufficient overlap in the performance of select tasks to ensure the timely availability of relevant information. Based on a sequence of activities characteristic of the design professions of architecture and landscape architecture, this book outlines a land development design process and resultant products that are sensitive to both client decisions as well as the general submission requirements associated with routine public review and approval procedures.

The level of detail and exact sequence required for submission documents for public review may vary from jurisdiction to jurisdiction, and different terminology may be used in identifying the documents. However, the traditional sequence of design resolution includes the following steps.

Site Assessment: Feasibility, Programming, and Site Analysis. This initial step in the process requires an understanding of the proposed development program and an overview of the site characteristics and surrounding area. The basic objective of the feasibility and programming stage is to become familiar with existing site conditions and the users' intended application on the site. The physical characteristics, including site configuration, topography, soils, hydrology, utility availability, and adjacent land uses are evaluated in the context of the client's proposed development plan.

The allowable use of the land must also be determined based on recommendations in the local government's comprehensive plan, as well as local zoning ordinances and other regulatory requirements that may influence the initial proposed development program, specifically the anticipated yield (either lots or floor area).

A site assessment is conducted to provide the designer and the entire design team with a complete understanding of the opportunities and constraints associated with a property. The results of the site assessment may offer opportunities to identify alternative development programs for review by the client.

Conceptual Design. The objective of the conceptual design is to establish a preliminary framework depicting the distri-

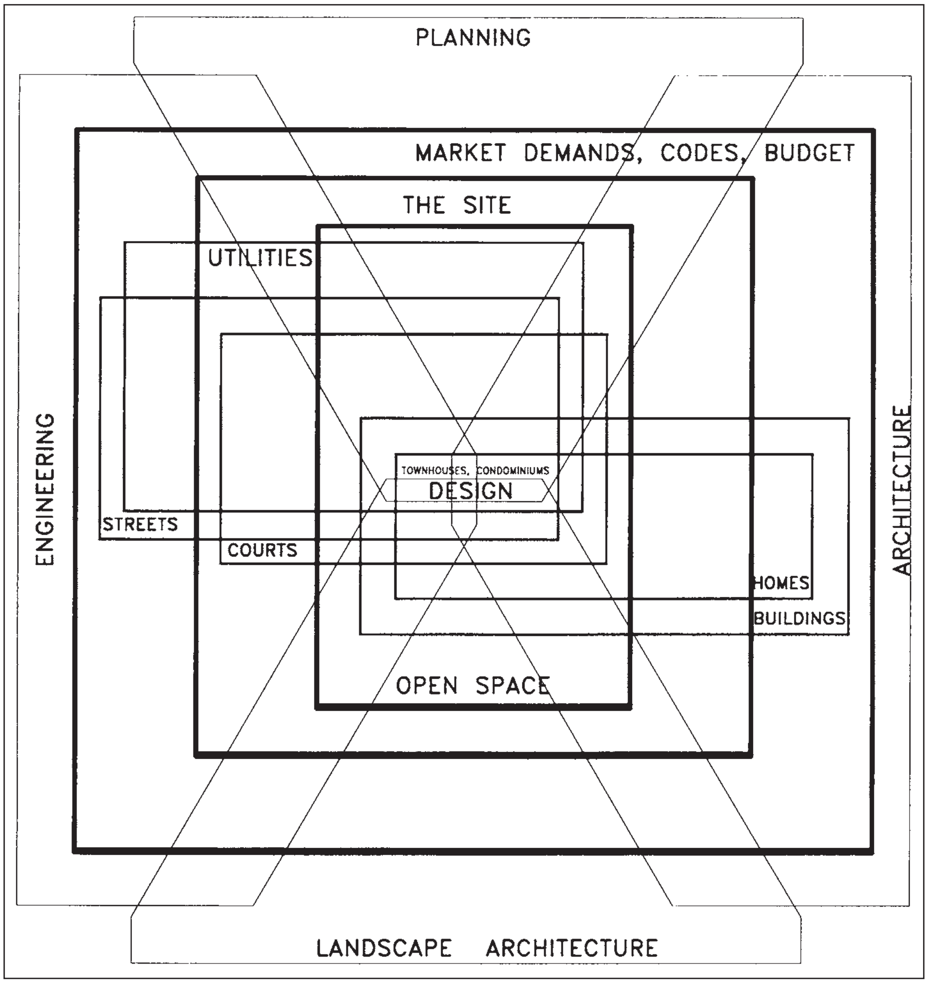

Figure 1.5 Overlapping disciplines of the design team. (Urban Land Institute 1979)

bution, organization, and arrangement of the development program. The conceptual design should honor the development constraints yet take advantage of opportunities identified in the site analysis stage. The resultant sketch plan (or plans) may include alternative strategies illustrating possible arrangements of principal land uses and infrastructure requirements. This exploratory stage deals with general distribution of uses. The sketch plan(s) at this stage are generally depicted as spatial arrangements or "blob" diagrams, which identify usable area, type of development, points of ingress and egress, site circulation patterns, and major infrastructure that may be required. This stage in the process is based on alternatives or what-if scenarios and proceeds to explore the alternatives to assist in formalizing the preferred project design. (See Figures 1.6 and 1.7.)

Schematic Design. This level of project design is a refinement of the selected conceptual studies that provide more precise scale and site detail of program components and supporting site improvements. The detail included in the schematic design is based in part on information obtained during the feasibility and site analysis stages and provides further assurance that the development program and goals can be achieved. Included in the schematic design is a site layout, which details and depicts the dimensions of the arrangement of program components. The site layout should confirm that the development plan is consistent with the goals and objectives established by the client and conforms to all regulatory requirements.

An important element of schematic design is preliminary engineering. The purpose of the preliminary engineering analysis is to verify and document the technical aspects of the schematic design. The result of this study is usually in the form of a graphic such as a preliminary site plan or a rezoning development plan. Checklists and/or reports are often prepared as well. These documents represent a final check of the development program prior to proceeding with more detailed final engineering.

Final Design. After the client and local governing agencies have reviewed and accepted the schematic design and preliminary engineering study, the civil engineers prepare the final design. The final design reflects the detail necessary for project review and approval by local governing agencies authorizing construction. The site plan developed during the final design represents the official documentation of the

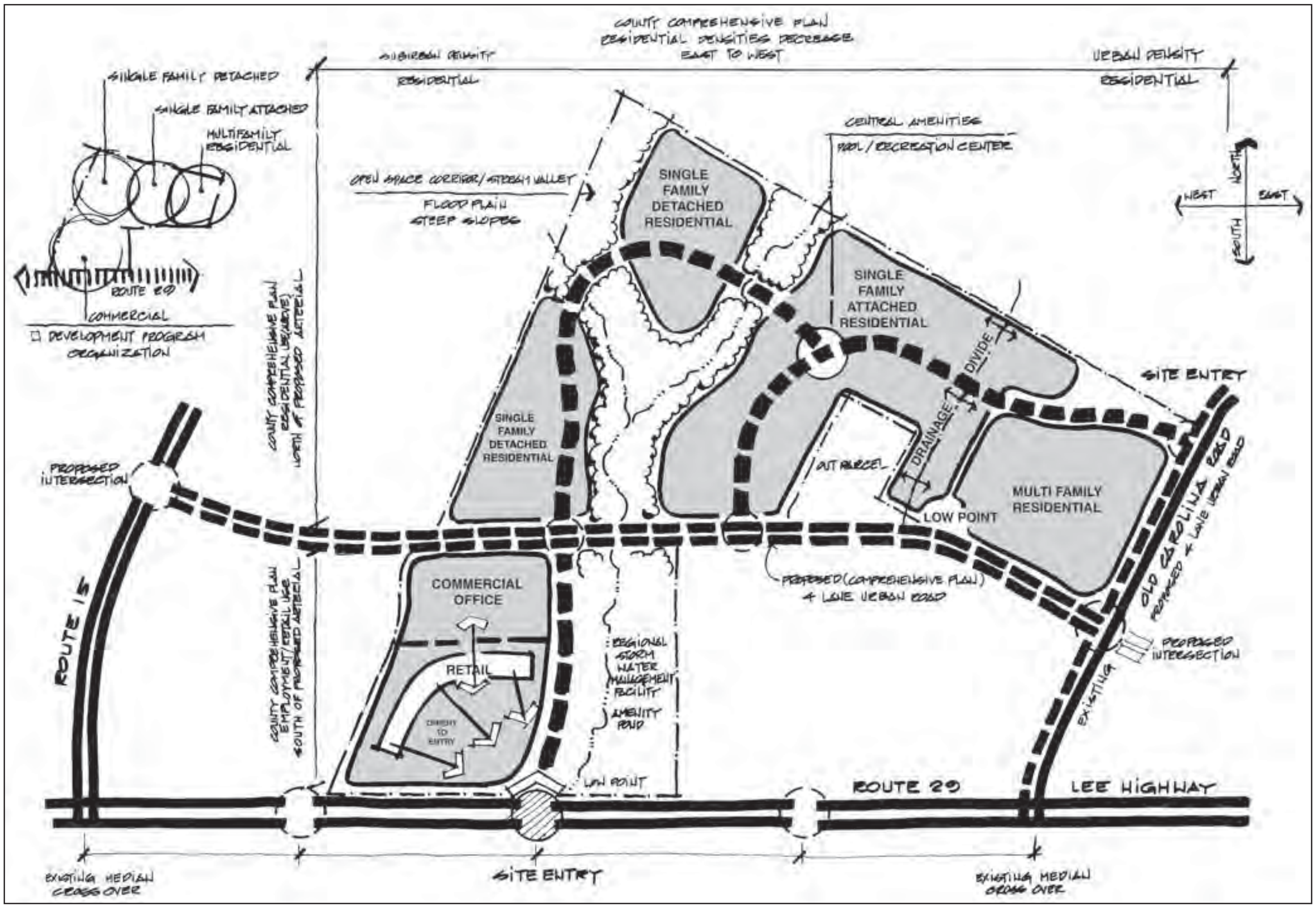

FIGURE 1.6 Bubble diagram.

land development design process. The main components of final design include the street design, storm drainage design, stormwater management design, grading and earthwork, wastewater collection, water distribution, dry utility design, erosion and sediment control, and, depending on the project, wastewater and water treatment facilities. Additionally, contract documents, construction specifications, and cost estimating are also developed at this stage.

Although the primary design process concludes with final design, land development consultants are often engaged to provide additional services including plan submission and permitting, construction, and postconstruction services. These subsequent steps in the land development process are increasingly important in terms of delivering a functional, aesthetically pleasing end product that meets the merits and intents of the design process. (See Figure 1.8.)

DESIGN: UNDERSTANDING OF BASIC REQUIREMENTS

The amount of reference material focusing on land development, and specifically project design, is extraordinary. Similar is the case with the volume of resource materials that more singularly focus on specific development and building prototypes such as residential, commercial, industrial, office, recreation, mixed-use, planned communities, waterfront, and golf course developments. Basic to the success of project design is the need for the designer to have an appreciation for the concepts and standards identified in that body of information. A design response premised on anything less must be recognized and valued as the technical solution it is. Historically, land development is steeped in technical solutions. These projects satisfy a multiplicity of functional and regulatory requirements inherent to site engineering and, ultimately, program constructability; however, they do not necessarily address the environmental, social, sensory, or visual dimensions, which are fundamental components of the built environment. Design solutions need to be based in a sensitivity to basic sociocultural, physical, economic, and political concerns, while reflecting the importance of economic and marketing constraints. In private-sector land development activity, a design must be capable of being constructed and it must provide a financial incentive to warrant its undertaking. No one profession possesses a monopoly on the diverse body of knowledge and resources required to achieve quality land development design. Land development is a process that is dependent on diverse disciplines and an extraordinary commitment to promote all aspects of the project with equal fervor.

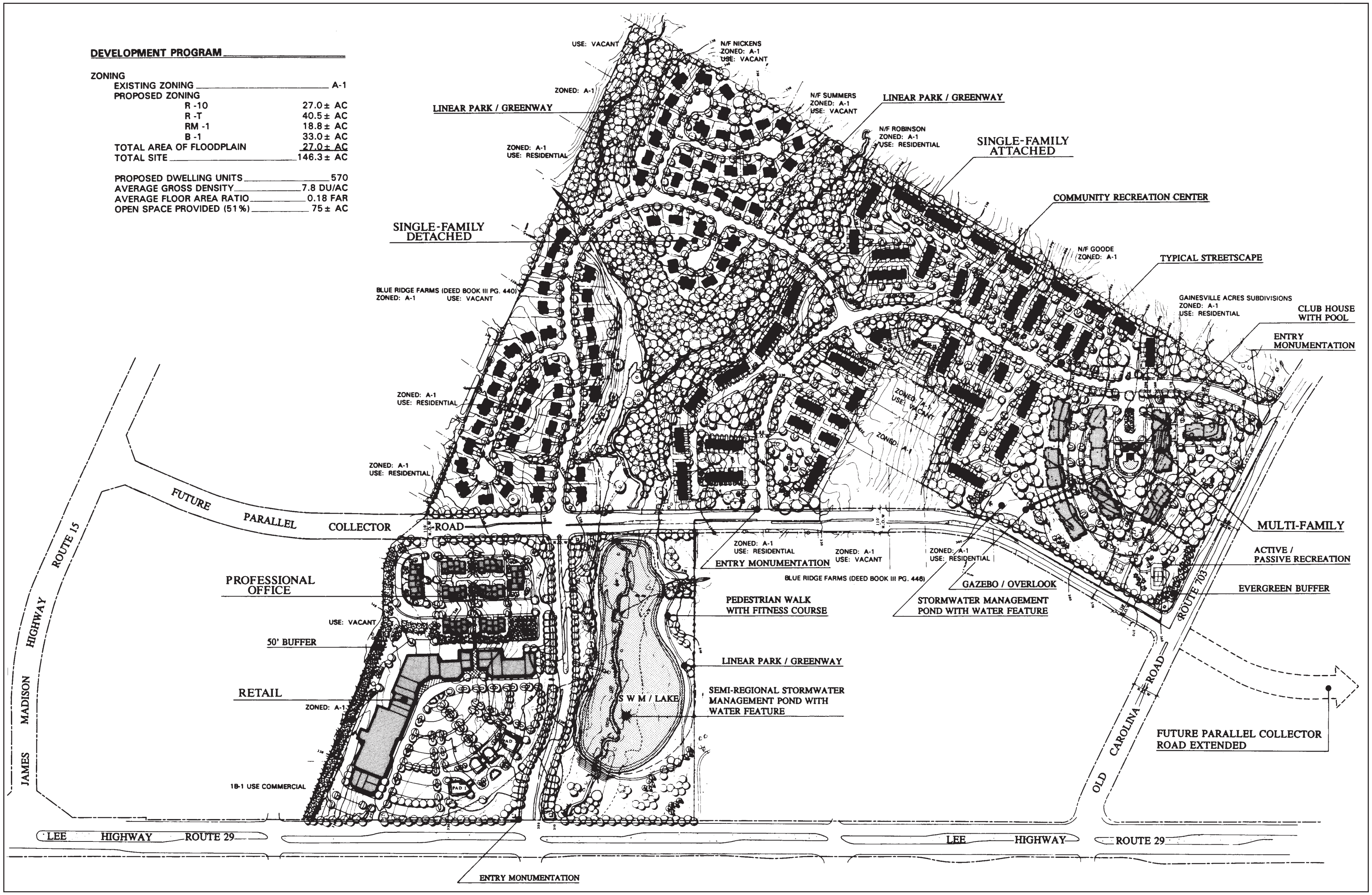

FIGURE 1.7 Concept plan.

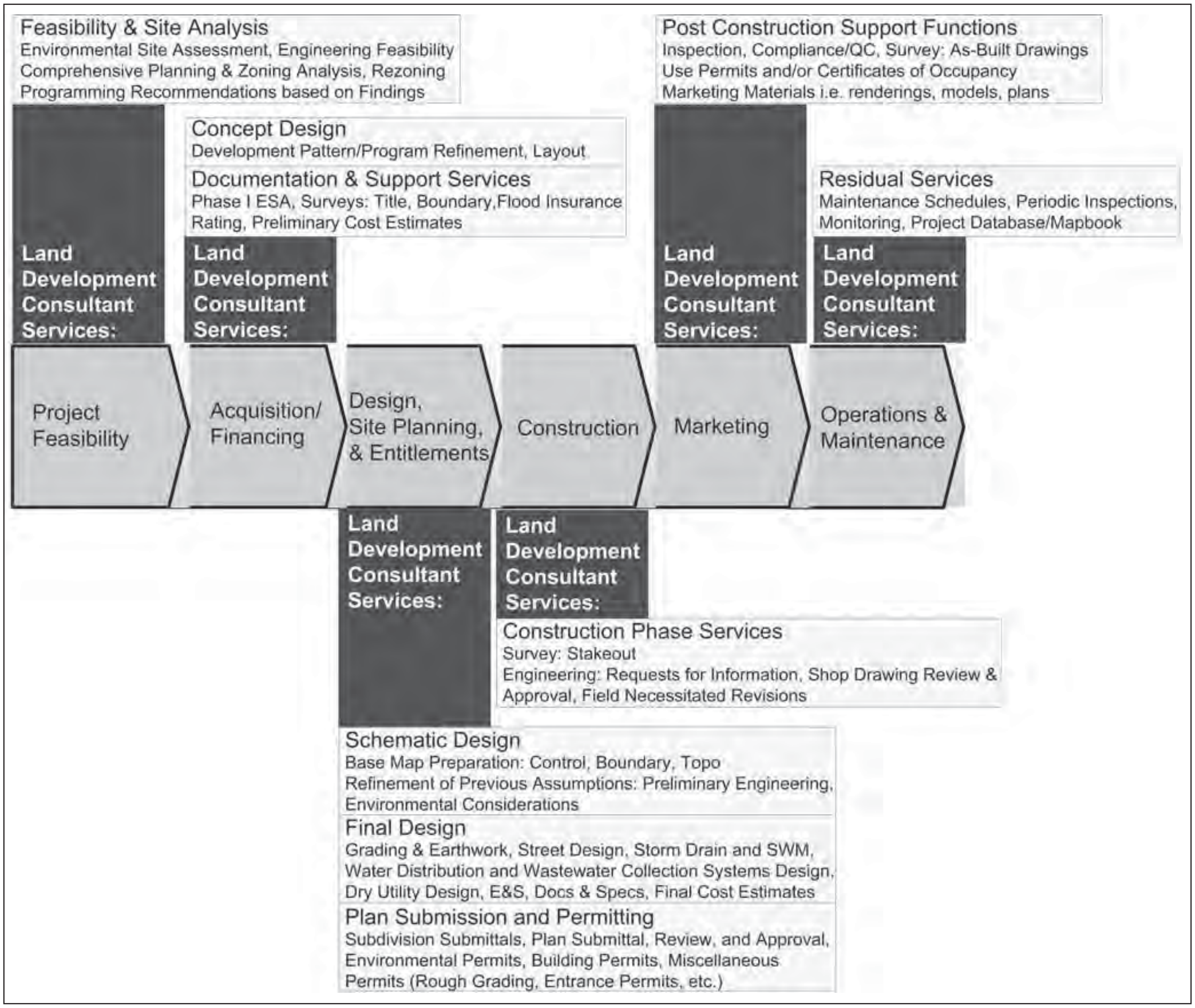

FIGURE 1.8 Real estate development process diagram emphasizing land development consultant services and deliverables.

Design Elements

Every development program is comprised of elements that define, shape, and establish the essence of that use. The constituent parts include both the physical—dimensional—building blocks that house principal activities, as well as the ancillary or support elements that are necessary to sustain the principal use. The former are the major space-taking elements that characterize a land use and its related building components. For example, the dwelling unit is the principal building module in residential development. The accessory uses include such considerations as connection to vehicular or pedestrian circulation systems and utility requirements necessary to maintain a certain quality of life—for example, water, sewer, power, and communications. Collectively, they constitute an operational whole. Project design must address all of these elements. There may be a number of ways to orchestrate a design that satisfies some of the basic requirements associated with a given land use or product type. However, the successful response seeks to reduce any conflict with program objectives and optimizes the relationship between all component parts. This approach applies to large-scale and mixed-use projects as well. The manner in which a site design response addresses these requirements should be a result of a conscious decision and not insensitivity to or neglect of any component or relationship.

Project design requires an ability to understand the relative needs and physical attributes of the program components. More homogeneous uses at lesser densities or intensities are generally more easily dealt with than mixed-use programs at higher densities. As an example, there is significantly more flexibility in siting a single-family residence on a large lot than there is for more dense residential projects. The challenge of site design rests in both knowledge of the requirements associated with a given land use or building type and an ability to make valid judgments and establish priorities as to which requirements should take precedence in formulating the design response.

Design Philosophies

It is neither the purpose nor the intent to discuss *all* issues that influence and guide the formulation of land development design. There are ample publications available to assist the designer in site- or product-specific design issues. The following discussion does, however, begin to annotate some of the design considerations necessary in establishing a framework for project design.

Conventional (Traditional) Design. Development of this type focuses on noncontiguous land development including subdivision-style residential development (0.33- to 1.0-acre lots) and strip nonresidential development (floor area ratios of 0.20 or less are common). These development patterns continue earlier trends of consumption of agricultural and sensitive environmental land (greenfields) and result in significant infrastructure construction including roads/pavement, water, sewer, and other utilities. While initial infrastructure construction costs are high, the end result is generally less-expensive single-family homes on large lots situated away from urban centers—this has been the longtime appeal of this form of development, as it appears to be an affordable avenue to the American dream. Further, a greater opportunity for participation in governance may be experienced in conventional developments due to the high number of small jurisdictions found in these peripheral areas (Burchell 2003). This approach is a highly vehicle-dependent form of development, given the underlying premise of conventional zoning or separation of uses. Recent studies have indicated that when housing costs (land, mortgages, utilities, HOA fees, etc.) *and* transportation costs are accounted for, the cost of living in these areas increases dramatically and even approaches or exceeds that of more urban (often perceived as more expensive) areas (Bernstein 2007).

Sustainable Design. An alternative design approach that is gaining momentum industry-wide for all land development applications, rural to urban, is a more compact form of growth that embodies the concepts of smart growth, low-impact development (LID), new urbanism, and resource conservation in an effort to promote managed, responsible growth. Sustainable design encompasses the entire design process starting with site selection (premised on smart growth, this design philosophy encourages growth around existing urban centers and limits it in peripheral rural and sensitive environmental areas) through final design and construction where LID techniques, material selection, and enhanced design integration between building and site systems are employed to minimize infrastructure requirements and optimize resource usage. Sustainable design tends to reduce infrastructure requirements for roads, utilities, and public services through higher-density, mixed-use development located within established service areas. Further, it attempts to encourage a variety of transportation options in addition to the automobile by providing services proximal to residential areas with attention to pedestrian and bicycle connections as well as an emphasis (again during the site selection process) on locating near transit. A greater array of housing is typically offered in areas close to urban centers and, as noted previously, when the cost of housing *and* transportation is assessed jointly, the result is often overall housing costs being lower in dense, urban areas in spite of lower peripheral single-family housing costs (Bernstein 2007). Disadvantages associated with this approach to development include: (1) increased housing costs owing to the land development limitations posed by managed, or smart, growth, (2) extra governmental costs stemming from the administrative requirements of imposing a growth management regimen, and (3) the thwarting or driving away of development potential because of an overcontrolled real estate market (Burchell 2003). Many also attribute higher construction costs to sustainable development projects, and, while this may be true, the increasing use of these concepts paired with improved overall familiarity with the approach by all involved in the land development process is contributing to a more streamlined design and construction process.

Projects (rarely) strictly follow one design philosophy over another. Given the many factors that influence a land development project, the design team often incorporates elements of both predominant approaches in order to meet the myriad requirements imposed from both clients and jurisdictions. It is important to be aware of the tools, technologies, and resources that exist to facilitate the design process and improve the end product: functional, beautiful, livable communities.

CONCLUSION

The Land Professional

With the advent of land use regulations, significant environmental constraints imposed by federal, state, and local governments, and the heavy involvement of citizens impacted by new developments, dedicated land use professionals must be prepared to draw on a wealth of resources to design a project that is appealing to both the end user and the surrounding community, yet be cost effective to the client. These professionals must be adept at balancing the objectives of the client with the expectations of the citizenry and public approval agencies. They must be prepared to handle a variety of projects, from the relatively simple conversion of vacant rural land to residential sites to the development of in-fill sites and complex, large-scale mixed-use projects.

The skills, innovative thinking, and creativity needed to make a land development project successful are gained through years of experience and encompass the entire spectrum of activities from land acquisition, rezoning, planning, engineering, and surveying to construction. The talents of many specialists including environmentalists, architects, surveyors, engineers, landscape architects, archaeologists, historians, geotechnical engineers, arborists, and land use attorneys, just to name a few, contribute to a project's success.

This Handbook

Undeniably, the land development design process, however systematic it is, varies considerably throughout the United States due to the diversity of state and local regulations controlling land use and land subdivision. Yet within the process there are many elements common throughout the jurisdictions. Similarities do exist. Even if it were intentionally written for a particular microregion, no book could present the specific design process because of the dynamics of the regulations. This book is a presentation of *a typical design process,* but in no way should it be construed as *the only design process.*

The authors hope that this handbook will aid land development professionals in anticipating the multiple issues and requirements they will no doubt encounter as they progress through the various stages of project development or as they seek to broaden their professional understanding of the complexities of land development. For developers, this book is an invaluable tool in understanding the services they will be acquiring from various design specialists and will prepare them for the regulation maze ahead. For those entering the land design profession, whether in the public sector or as a consultant, this handbook aids in developing the skills needed to be a successful, contributing member of a land design team. For practitioners, it will prove a treasured reference tool.

The following chapters together constitute a practical guide to the land development industry, detailing the intricacies of each discipline while providing a comprehensive view of the process as a whole including the interrelationships among various disciplines. This book answers technical questions and provides next-step guidance through the entire land development process. Systematic implementation of this design process by creative, passionate, and dedicated professionals is the basis for successful land development projects.

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PART II

FEASIBILITY AND SITE ANALYSIS

When a parcel of land is being developed, feasibility and site analysis seemingly go hand in hand. Typically, the client (developer) will request both simultaneously or in near concurrence to one another. While the book's format groups these steps together, they are addressed separately in the following brief introduction to delineate their differences and indicate how each step serves a distinct purpose in land design.

STEP 1: FEASIBILITY

The feasibility effort requires investigation and documentation along two main avenues: (1) evaluation of existing site resources including confirmation of micro and macro site characteristics and (2) establishment of project goals and intent in terms of program components and specific design priorities such as green building certification requirements or other client-driven criteria. Once this information base has been established for a specific site, the formulation of a design response can proceed.

Usually the designer is charged with several important tasks that will assist in initial development discussions. These include:

- Preparation of a rough base map for initial field investigations. Ideally, a property survey and topographic map will be available from the client. If not provided by the client, boundary information available through local property tax map sources (often online) and topographic mapping, which may have been compiled by local jurisdictions (typically 1 inch:200 feet with 5-foot contour intervals) or the U.S. Geologic Survey (typically 1 inch:2000 feet with 10-foot contour intervals), should be obtained. The designer should continually be aware of scale and accuracy limitations imposed by secured base information.
- Assembly of secondary source information that will assist in determining the quality and condition of existing infrastructure systems and their relative ability to support the proposed development program. Current road, utility plans, and public facility plans are important and should be analyzed during the feasibility and programming step to assess available capacity and potential improvement requirements. If previously performed preliminary feasibility studies are available, they should be reviewed and the accuracy of the information corroborated.
- Contextual and physical assessment of the site and its surrounding area. A field visit is the best means of ensuring site familiarity. This should be done with a base map in hand on which appropriate annotations can be made in the field. The visit should ideally be completed after a review of previously available site data to provide the designer with a sense of what to expect on-site as well as allow for field verification of previously compiled information. A current quality aerial photograph can be of immeasurable assistance in verifying preliminary information and augmenting site research and field observations. Aerial mapping is publicly available online through Google Earth or Windows Live Local. Information regarding adjacent and proximal properties is helpful in evaluating the client's proposed development program and should be examined and/or confirmed through the field visit and research efforts.

During this phase, the design team reviews all available feasibility and impact studies that might previously have been undertaken for a given property. The designer and other members of the design team work with the client to fully explore and describe the proposed development program in conjunction with preliminarily identified site opportunities and constraints.

STEP 2: SITE ANALYSIS

The purpose of the site analysis is to provide the designer with a full understanding of the potential or allowable use of a property. A thorough review of current planning and regulatory controls is performed. This includes identification and analysis of the following documents as they relate to the particular site:

- Comprehensive plan
- Zoning ordinance
- Subdivision regulations
- Other relevant land development ordinances identified in the local code
- Previous development proposals affiliated with the site or adjacent properties.

Initial research efforts may also include preliminary meetings with local officials and/or community members in order to gauge the social and political climate surrounding the site. It is important at this early stage to thoroughly understand the client's confidentiality limitations—program components are very preliminary and land transactions are sometimes tentative. Therefore, these discussions should be forthright but tempered with respect to the client's interests.

SITE ASSESSMENT

The end product of the feasibility and site analysis step is the completion of an overall site assessment. This assessment focuses on the identification of development opportunities and constraints associated with the subject site, particularly potential red flags, or site features/conditions that would prohibit the desired development scenario. Ideally, the site assessment (or inventory) notes should be on a base map that is at the same scale as the ultimate conceptual design studies. Typically, the assessment is conducted following the establishment of the proposed development program and parameters that allow for realistic consideration of the property. While this is not always possible, it is advantageous to conduct more intensive site investigation after the initial range of desired uses for a given site has been established. The checklist of site characteristics that may have potential consequences for later site design include the following characteristics and associated considerations:

- Topography, slope, and soils
- Property configuration
- Existing vegetation
- Hydrology, drainage, water, wetland, and floodplains
- Views and visual characteristics
- Climate, site orientation, and exposure
- Adjacent land uses
- Access, potential, and circulation patterns
- Utility locations and existing easements
- Comprehensive plan designation
- Zoning restrictions
- Existing development encumbrances on the site
- Other regulatory requirements such as the Fair Housing Accessibility Guidelines and the Americans with Disabilities Act Accessibility Guidelines, which typically have significant consequences for site layouts

Following the assessment of the site characteristics listed here, the results are generally presented in a series of exhibits, maps, diagrams, and/or reports that document the site's development opportunities and constraints. Figure II.1 provides examples of the various site assessment maps that could be developed to illustrate site characteristics. An example of a composite map, or site inventory, is provided in Figure II.2.

In conclusion, the site assessment should provide an overview and initial delineation of those portions of the site that are *capable* or *not capable* of supporting various elements of the development program. This assessment should result in an ability to quantify areas of the site deemed usable for program development. Often this quantification is referred to as the *net buildable area* of the site. It represents that portion of the entire gross acreage of the site that the designer and other members of the design team have determined can reasonably be used in the proposed development program.

Appreciation of Program

As part of a multidisciplinary team, the designer may be an initial participant in orchestrating the research and background information that lead to describing the development program. However, with increasing frequency the program is being spearheaded by the client alone or in concert with his or her market consultant. The designer is, however, in a unique position to assist the client team in refining the use associated with the development program based on site characteristics and public planning, land use, and regulatory controls.

In order to secure a firm understanding of the development program, the designer should elicit from the client as much information as possible at the inception of project design. It is insufficient to begin design activity mindful only of the generic or seat-of-the-pants agenda of land use types desired. Clients generally have strong, preconceived ideas

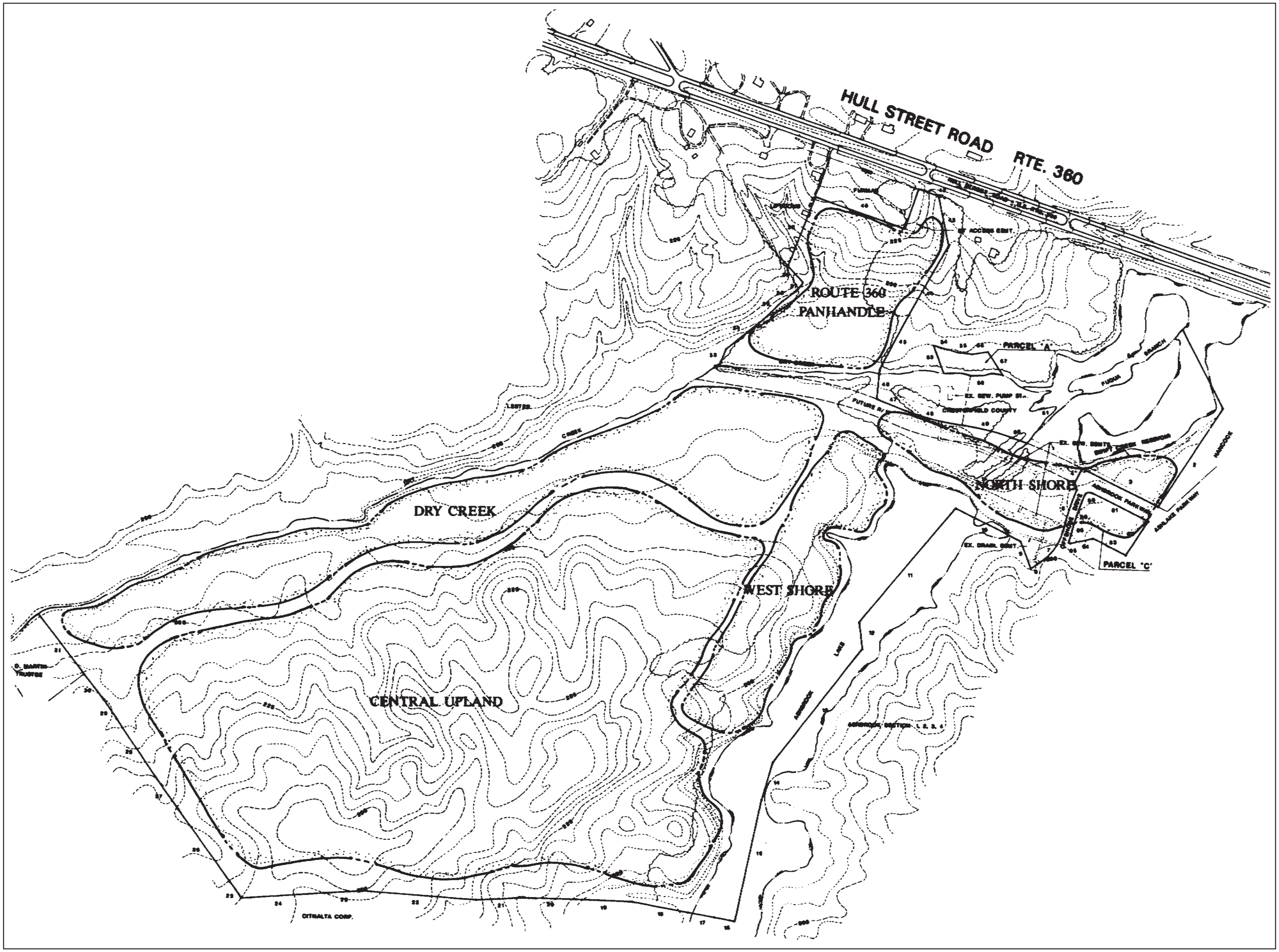

Figure II.1 Example of series of site analysis (seven maps).

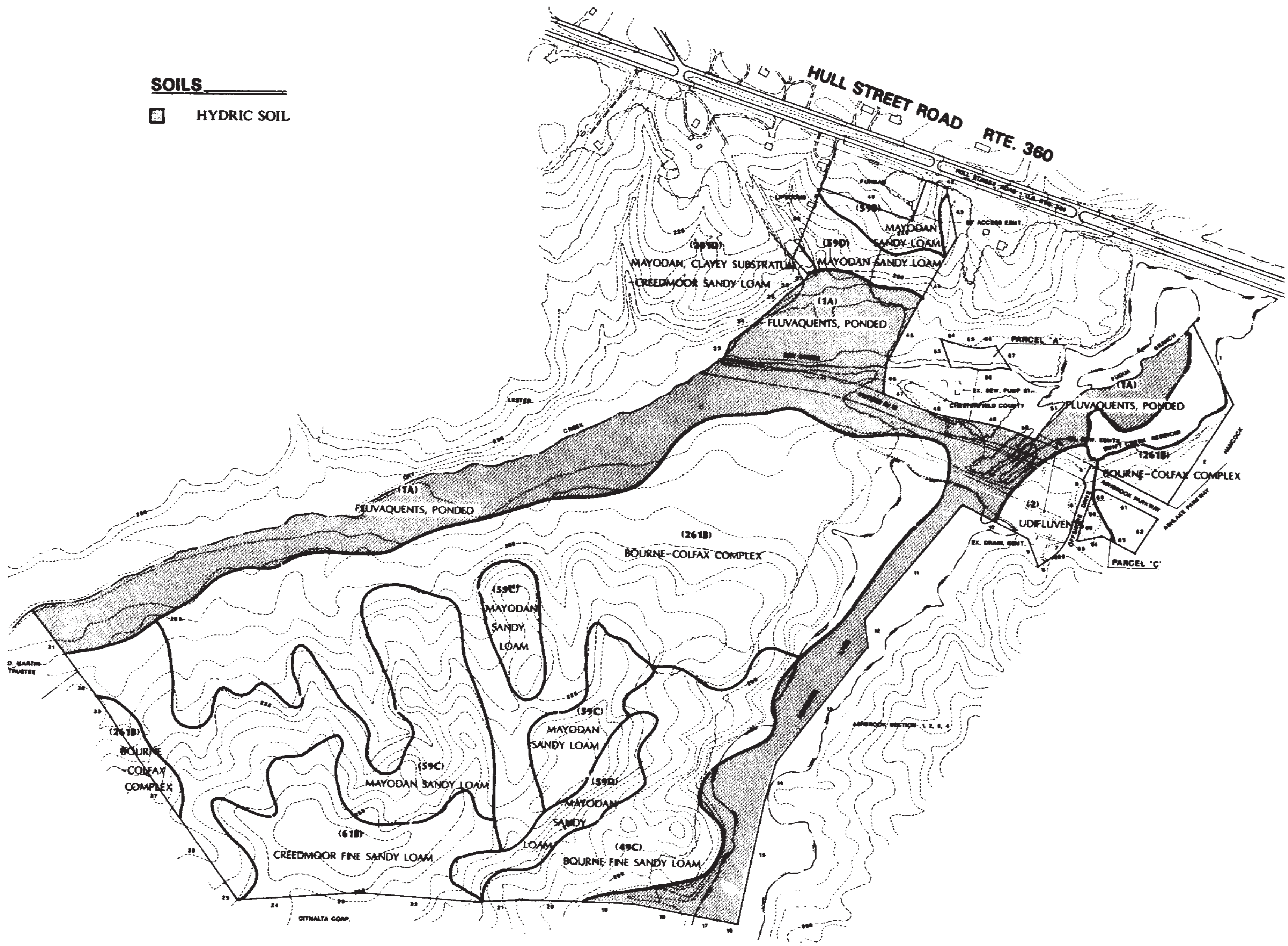

Figure II.1 *(Continued)*

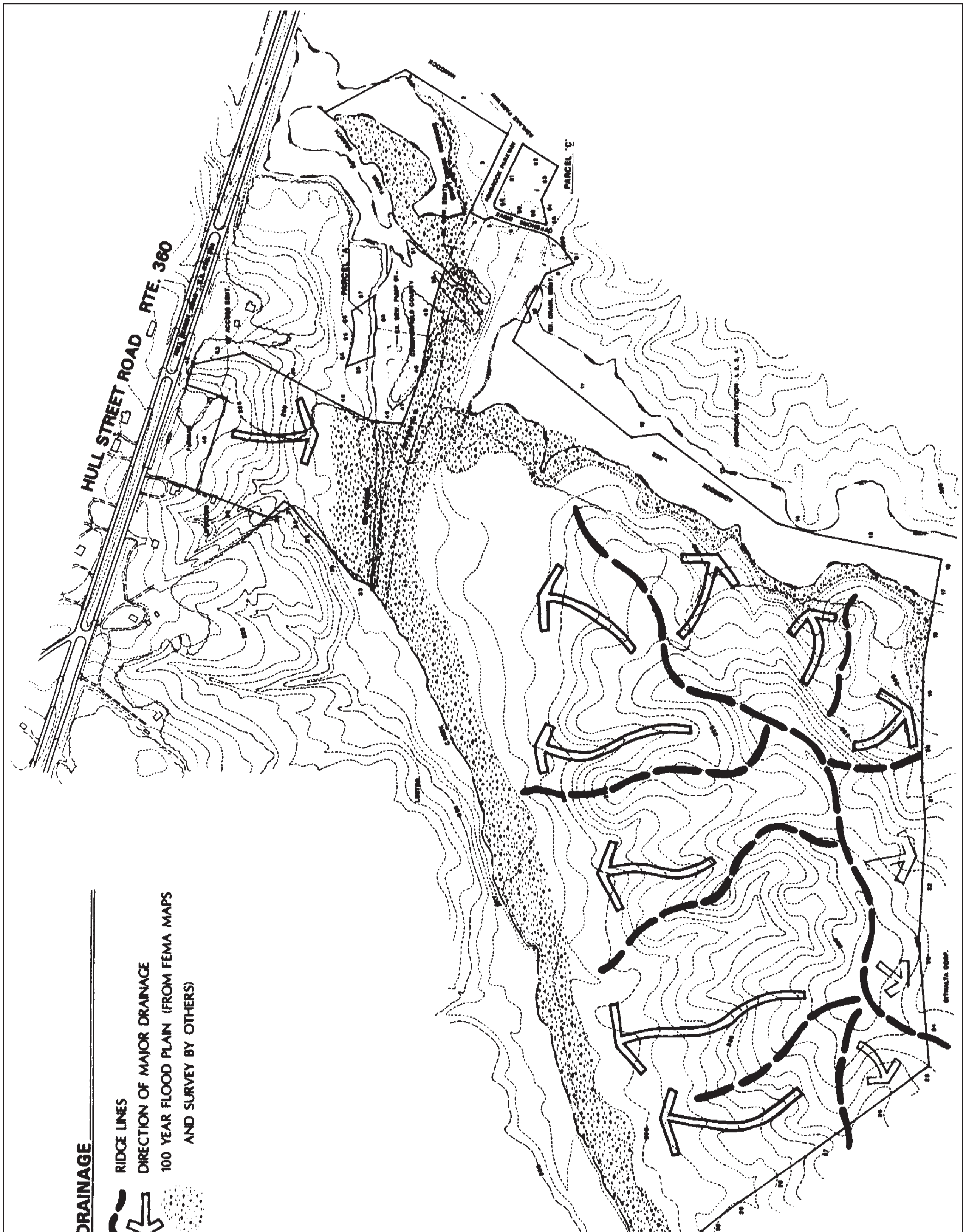

FIGURE II.1 *(Continued)*

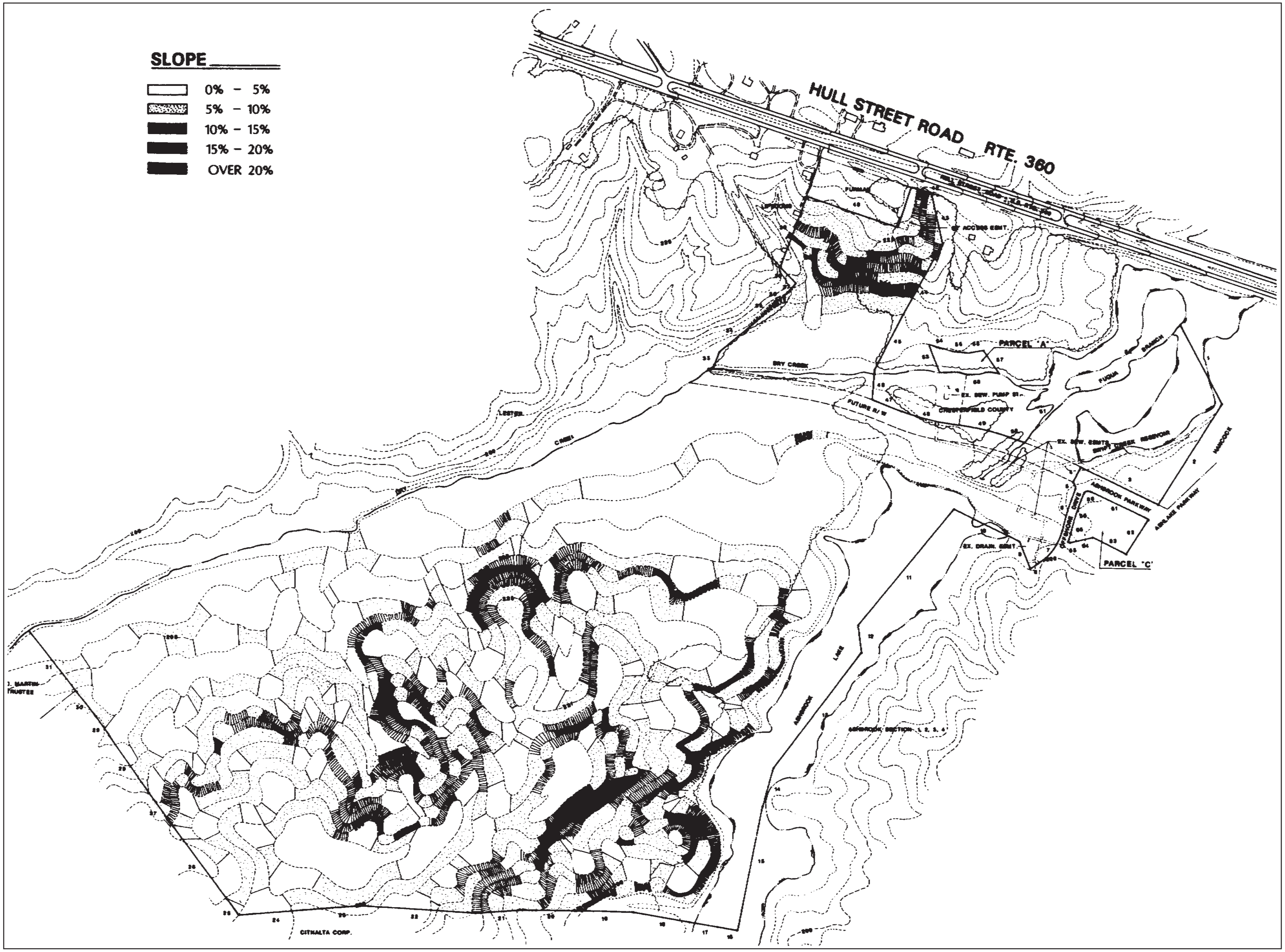

FIGURE II.1 (*Continued*)

Figure II.1 *(Continued)*

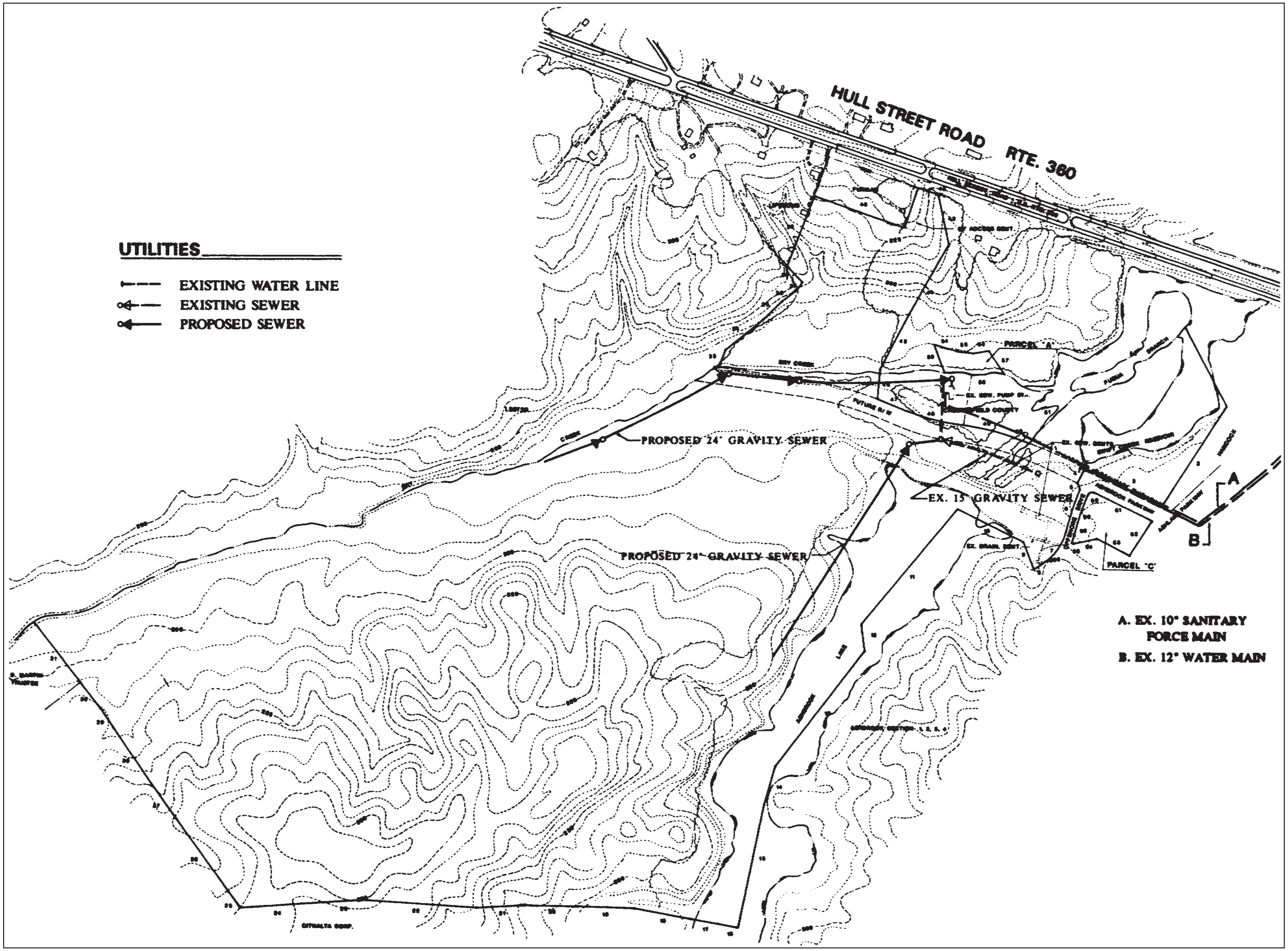

FIGURE II.1 (*Continued*)

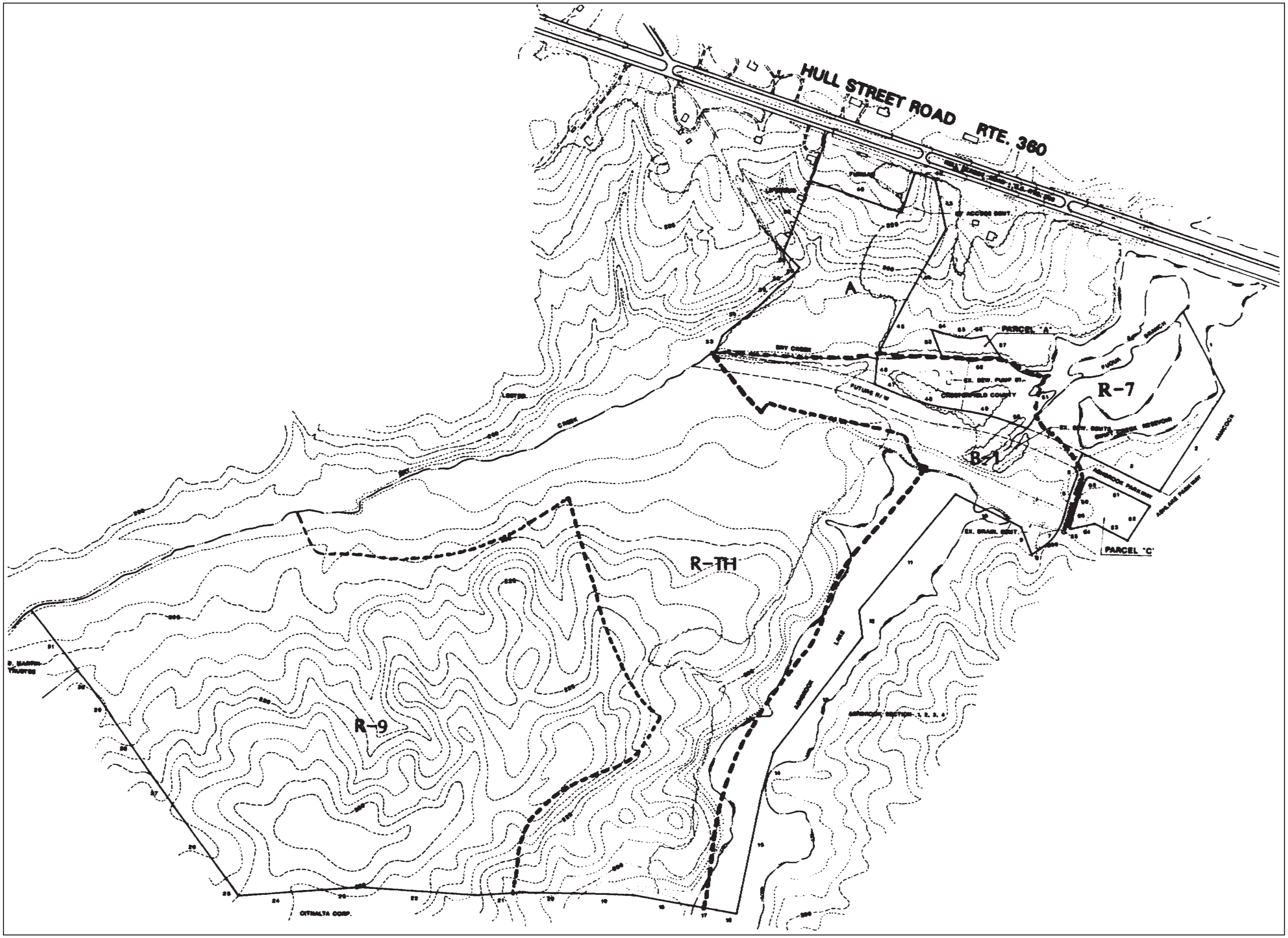

FIGURE II.1 (*Continued*)

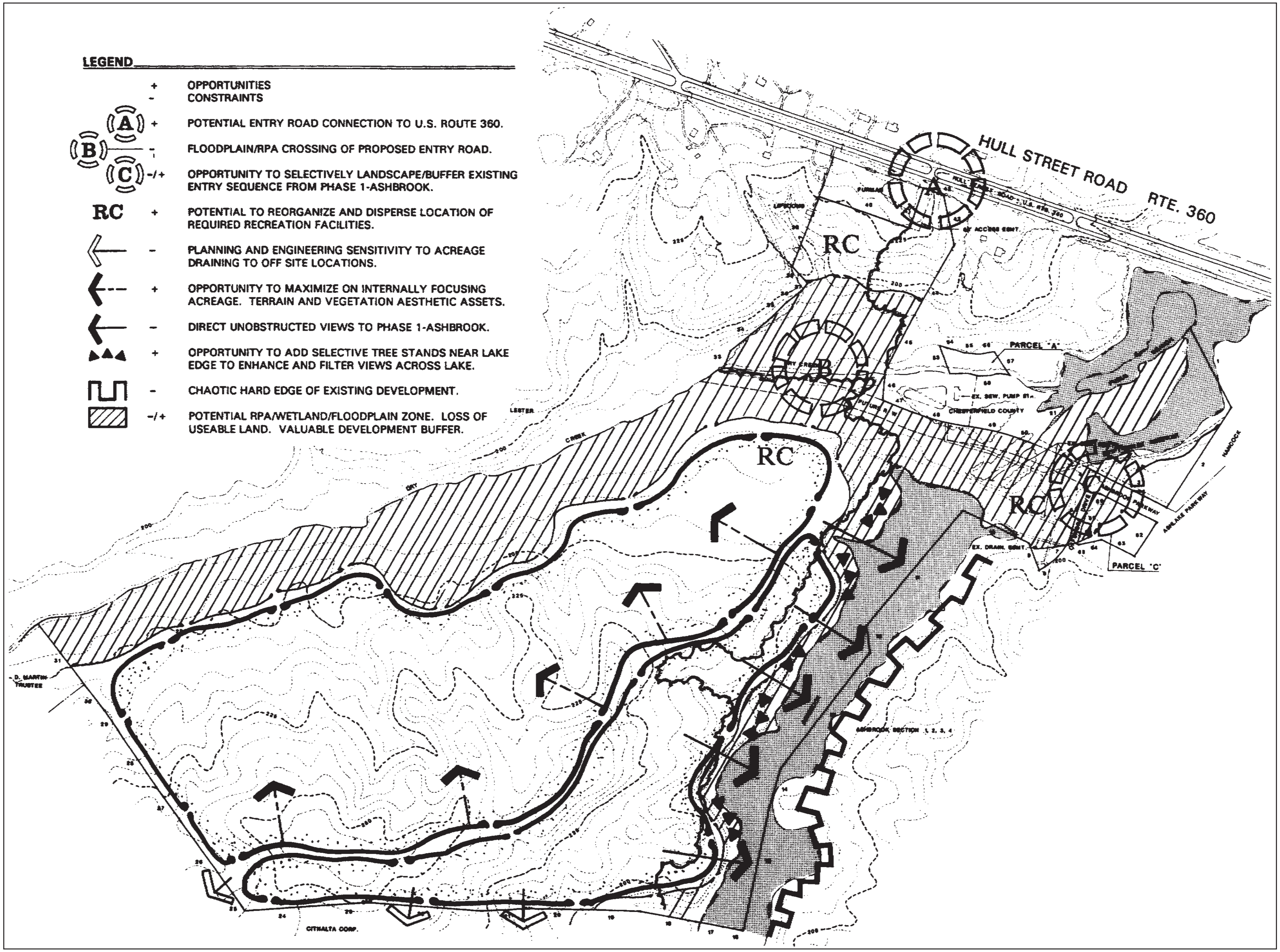

FIGURE II.2 Example of composite map showing opportunities and constraints analysis.

regarding the character of the project they wish developed. At a minimum they can relate their expectations relative to existing projects they believe most resemble their current proposal. Even the most unseasoned client has certain base development objectives that have prompted the initiation of a specific development effort. The designer should discuss these expectations with the client, including an inventory of objective criteria such as unit or building type, building dimensions, architectural finish, parking ratios, amenity elements, sustainable or green building design goals, and more subjective statements regarding the desired character or ambiance of the finished product. Although clients often indicate the density or intensity of the development they desire, more often than not it is insufficient to initiate a site design. Most clients have completed at least a rudimentary assessment of the possible return on their investment for a project prior to the initiation of discussion with a design team. The design team should attempt to verify the anticipated yield and green building certification level (if a priority) as well as preliminary budgetary allowances for such items as utility construction, amenity development, and landscape, to better understand the anticipated character and quality of development.

It is similarly important that program objectives be discussed in the context of existing planning and regulatory controls. Land use type and use intensity should be reviewed with a clear understanding of existing jurisdictional comprehensive plans and zoning. Based on this discussion, the development program or alternative programs should reflect a realistic proposed land use. Ultimately, the success of a site design is measured to the extent that it optimizes client objectives against those of public-sector expectations and standards. It benefits no one to foster questionable expectations associated with unreasonable program formulation.

This step is a precursor to design. It is, in reality, an information-gathering stage, but information gathering with specific purpose and direction. Information is expensive to compile and time consuming in its review. Therefore, it is important to undertake the site assessment effort with a clear focus on the judicious expenditure of time and resources. At this juncture in the design process, all available existing information, including base maps, aerial photographs, engineering information and controls, and planning reports, should be assembled.

The end product of this phase of project activity includes a clear understanding of the proposed development program and options, the identification of site constraints and opportunities, assurance that all regulatory requirements can be satisfied in conjunction with refinements to the proposed development program, and a positive finding that the physical and functional characteristics envisioned by the client can be realized.

PART II.A. FEASIBILITY AND PROGRAMMING

CHAPTER 2

ENVIRONMENTAL POLICY AND REGULATIONS

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Updated/Revised: Christina Gray

INTRODUCTION

Land development is faced with the issues of satisfying demands of human needs while also meeting the requirements of environmental restoration and preservation. Our past actions as a society have resulted in significant impacts to the environment due to human consumption and the mismanagement of our natural resources and hazardous waste. To prevent continued degradation of the environment, environmental regulations were established to ensure responsible actions toward the protection and maintenance of the environment.

Land development processes involve many activities that have environmental impacts. Site selection, planning, grading, construction, and landscaping all require many decisions that shape neighborhoods, towns, and regions in profound ways. These decisions result in changes to the existing landscape that are long term (in human scale) and commit natural resources in a way that affects future options. As these decisions have become more and more complex, natural ecosystems have not been able to accommodate the outputs of development. Consequently, government environmental policies and regulations were developed to preserve a quality of life for our citizens through vital natural resource protection, preservation, and/or mitigation strategies. Regulations have allowed standards to be set, which prevents ad hoc actions with uneven consequences. This has allowed for land development to proceed with managed consequences while improving overall environmental conditions.

This chapter traces the development of environmental policy and regulations in the United States as they affect land development; it is not intended to be exhaustive or all-inclusive, as there are regional, state, and even local policies that shape development projects from conception to actualization. The reader must bear this in mind and become familiar with the agencies and regulations at all levels that may affect development in a particular locale.

ENVIRONMENTAL POLICY

In the 1960s, as a result of deteriorating environmental conditions and serious health effects associated with those conditions, the time was right for national discussions of how to effectively address these problems. The National Environmental Policy Act (NEPA) was signed into law on January 1, 1970, and it became the catalyst for the environmental regulations that were to follow. NEPA is the declaration of the United States's policy on the environment. This national policy attempts to balance the preservation of the natural environment and human needs resulting from population increases, high-density urbanization, and industrial expansion by taking into account economical and technical considerations. The declared purpose of NEPA is as follows:

> To declare a national policy which will encourage productive and enjoyable harmony between man and the environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.

With this declaration, six national goals were established:

1. Fulfill the responsibilities of each generation as trustee of the environment for succeeding generations
2. Assure for all Americans safe, healthful, productive, and aesthetically and culturally pleasing surroundings

3. Attain the widest range of beneficial uses of the environment without degradation, risk to health or safety, or other undesirable and unintended consequences

4. Preserve important historic, cultural, and natural aspects of our natural heritage, and maintain, wherever possible, an environment which supports diversity and variety of individual choice

5. Achieve a balance between population and resource use which will permit high standards of living and a wide share of life's amenities

6. Enhance the quality of renewable resources and approach the maximum attainable recycling of depletable resources

These goals establish the broad national framework for protecting our environment.

The Council on Environmental Quality (CEQ) was established in the executive branch of the federal government to develop and analyze national and international environmental policy and to issue guidelines on the implementation of NEPA.

The Environmental Protection Agency (EPA) was established in the legislative branch of the government to set standards and enforce environmental regulations. While NEPA sets policy goals, the regulations of the EPA are the prescriptions and methods to achieve those goals. The EPA is charged with the responsibility for federal laws and rule making to implement U.S. environmental policy.

Federal Laws and Rule Making

Most laws passed by Congress are statements of policy broadly outlining what the law prohibits or allows, as well as the penalties for noncompliance. These laws are found in the United States Code (USC), Public Law (PL), and the Code of Federal Regulations (CFR). The executive branch department or agency assigned responsibility by Congress for enforcement of the law develops rules or regulations designed to implement the legislation. The rules or regulations describe the allowed and prohibited activities, detail procedures for permitting, and document the consequences of violation.

All final regulations of the federal government are published in the CFR. The CFR is organized into titles, with titles divided into chapters. Chapters are further subdivided into parts, and parts into subparts. For example, the regulations the EPA has promulgated are included under Title 40, Protection of Environment, Chapter I, Parts 1 to 799. The CFR, published yearly, and the *Federal Register* are available at most large libraries and on the Internet simply by searching for the home page of the responsible agency and then searching for "Regulations."

ENVIRONMENTAL REGULATIONS

Environmental regulations are the mechanism for implementing the intent of the various acts and statutes developed to protect human health and the environment. The challenge for developers is that these regulations are extremely diverse; they are also continually being updated and revised. Therefore, a developer must take the necessary steps to ensure compliance in order to minimize liability and avoid unanticipated costs and delays associated with the purchase and/or development of a property.

A brief summary of environmental regulations over the last few decades can put into perspective the progression of environmental regulations and their future focus. The 1970s were a decade of extensive new federal legislation covering all aspects of environmental issues. The 1980s emphasized refining existing legislation and enforcement policies. The 1990s emphasized balancing economic and environmental costs through risk assessments. The new millennium has looked to reutilization and improvement of contaminated areas (brownfield development), green building and designs for sustainability (see Figure 2.1), and consideration of the possibility of global warming.

Developers are faced with issues such as smart growth versus urban sprawl. One of the challenges is that both have environmental impacts. Urban sprawl threatens to reduce the limited amount of undisturbed/undeveloped land impacting our natural resources, and the increased traffic volume results in more pollution. Conversely, smart growth has the potential to increase noise pollution and cause higher pollutant loads in a more concentrated area. A developer has to deal with these and other significant environmental issues to strike a balance between the demands of human needs and environmental regulations.

Many of the environmental statutes that work together to address hazardous waste concerns and the protection of our natural resources are briefly discussed in the following text. The regulations most likely to have financial implications and project impacts for a developer are NEPA, which establishes the need for and extent of environmental assessments; the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which focuses on the response to existing environmental conditions; and the Clean Water Act, which regulates wetland impacts and sets land disturbance permit and stormwater treatment requirements. Actual references to specific CFRs can be found in specific sections describing these regulations later in this book. These acts can be further researched by accessing the Congressional Research Service through a website maintained by the National Council for Science and the Environment at www.ncseonline.org/nle/crs/.

Other environmental regulations protect natural resources and the functions they provide. Their focus is on pollution prevention and the prevention of natural resource damages. A more detailed discussion of some of the major environmental regulations of particular interest to land developers follows.

Fish and Wildlife Coordination Act (1934, as amended through 1965)

This act recognizes the vital contribution of our wildlife resources to the nation. Wildlife resources are defined as

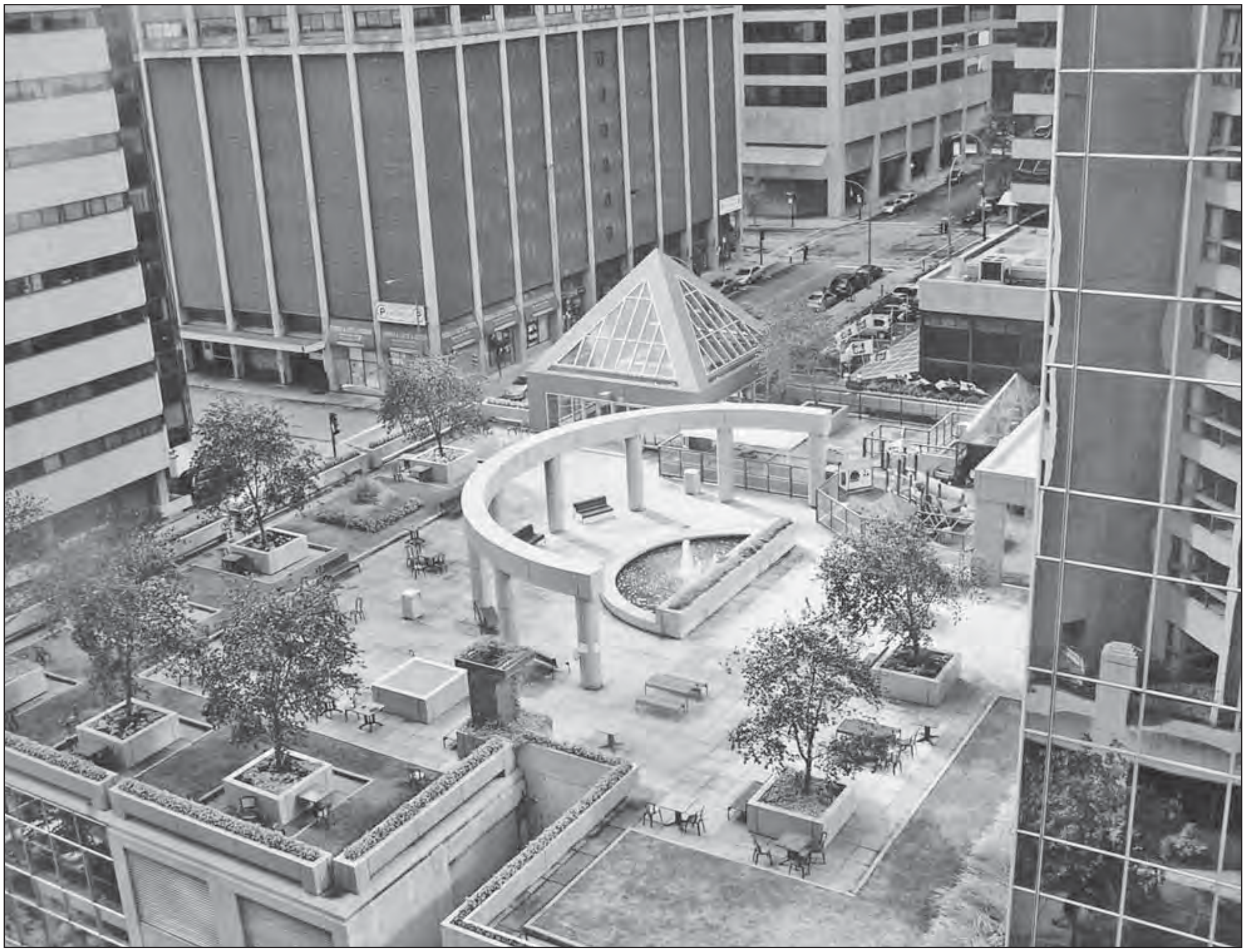

FIGURE 2.1 Green roof provides aesthetic and energy-saving benefits. (Photo courtesy of Christina Gray)

birds, fish, mammals, and all other classes of wild animals, as well as their habitat. It establishes the need to coordinate activities of federal, state, local, and private agencies with the U.S. Fish and Wildlife Service to ensure the development, protection, and stocking of wildlife resources and their habitat. This act authorizes the preparation of plans to protect wildlife resources. Any report recommending authorization of a new project must contain an estimate of wildlife benefits and losses and the costs and amount of reimbursement required.

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA; 1947, as amended through 1991)

FIFRA regulates the use and safety of toxic pesticides that are produced. FIFRA requires each pesticide to be registered with the EPA prior to commercial manufacture. Distribution of any pesticide that is not registered or that is improperly labeled is prohibited. In determining whether to register a pesticide, EPA considers the economic, social, and environmental costs and benefits of use of the pesticide. (See Figure 2.2.)

Clean Water Act (CWA; 1948, as amended through 1987)

The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of our nation's water. One of the major focuses for the national water program is to control point-source discharge of pollutants to water through use of total maximum daily loads (TMDLs); this regulates the amount of pollutants permitted to be discharged to waters of the United States. Water supply and water pollution issues also include non-point-source controls and effective use of water resources management practices.

Sludge resulting from wastewater treatment and pretreatment under CWA must be handled at a Resource Conservation and Recovery Act (RCRA) facility if it is hazardous. Discharges from an RCRA-permitted facility must be pursuant to a National Pollutant Discharge Elimination System permit. This means that either the facility has obtained an NPDES permit or the waste meets CWA pretreatment standards and has been transported to a privately owned treatment works.

National Pollution Discharge Elimination System (NPDES). Mandated by Congress under the CWA, the NPDES program addresses the nonagricultural sources of stormwater discharges that adversely affect the quality of our nation's waters. The CWA requires an approved NPDES permit to discharge pollutants through a point source to surface waters. Point sources are discrete conveyances such as pipes

Figure 2.2 Essential pollinating species must be protected from inappropriate pesticide use. (Photo courtesy of Christina Gray)

or man-made ditches. The permit provides limits on what is being discharged, monitoring and reporting requirements, and other provisions. Generally, the NPDES permit program is administered by authorized states.

Construction activities are considered an industrial activity and, as such, will typically require an NPDES permit. Specifically, an NPDES permit is required if the construction results in the disturbance of more than 1 acre of total land area. However, some jurisdictions may have more stringent requirements based on regional or local environmental concerns; for instance, in the Chesapeake Bay watershed, 2500 square feet of disturbance triggers the requirement for a permit. Construction activities that require a permit may include clearing and grubbing, grading, and excavation. These activities are typically associated with road building, borrow pit excavation, residential housing construction, office building construction, light industrial construction, or facility demolition. In some states, a permit may not be required if the runoff does not discharge into a waterway, as in the case where it evaporates from a catch basin or similar isolated water body.

Additionally, as a result of the NPDES permit program, construction sites are required to have a Storm Water Pollution Prevention Plan (SWPPP) prior to commencement of any land-disturbing activities. Phase I of the program was promulgated in November 1990 and covered construction sites greater than 5 acres in size. Phase II of the program, initiated in November 1999, requires operators of construction sites from 1 to 5 acres to obtain a permit. The goal of the SWPPP is to maximize the potential benefits of the pollution prevention and erosion and sediment control practices through the use of best management practices during the construction process. Since the primary focus of this program is on controlling pollutants in any stormwater discharge, incorporation of well-thought-out and carefully implemented erosion and sediment control measures is more important than ever.

Wetland Regulations. Many development projects impact stream channels or wetlands that constitute waters of the United States and, as such, are regulated by the U.S. Army Corps of Engineers (Corps) under the CWA. As written, the CWA's Section 404 statute regulates the discharge of dredged or fill material into navigable waters of the United States. As a result of a lawsuit settlement in 1975 (*Natural Resources Defense Council v. Calloway,* 392 F. Supp. 685 D.D.C 1975), jurisdictional authority was extended to nonnavigable waters and wetlands. This authority has been challenged several times as to the actual jurisdictional reach intended by the CWA, and it continues to be challenged today. Recently, the Corps and state agencies have shifted their regulatory focus onto stream channel impacts, including intermittent and ephemeral streams as well as wetlands.

Each of the individual states has a role in the federal permitting process through the authority of Section 401 of the CWA. The state must certify that the granting of a 404 permit by the USACE will not violate state water quality standards. Depending on the particular state and the type of project, an individual water quality certification may be required or the project may qualify for a blanket certification issued by the Corps for certain activities. Some states have their own wetland permit program based in part on their authority and responsibilities under Section 401.

Many states have initiated programs to protect wetlands and other waters from a range of activities that the federal Section 404 regulations do not address. Typically, state wetland protection laws regulate draining, channelization, or clearing of vegetation. (See Figure 2.3.) In addition, some states have gone further to protect those areas by requiring buffer areas adjacent to wetlands to prevent damage to the resource. Many states have used the authority to issue or deny water quality certification under Section 401 of the CWA to regulate some fill impacts to wetlands and other waters of the United States, including intermittent streams. A state can deny water quality certification of a proposed impact under the premise that the state's water quality standards are not being met.

The federal review of a permit application to fill or alter wetlands follows the guidelines of Section 404(b)(1) of the CWA. The use of these guidelines is addressed in the February 6, 1990, Mitigation Memorandum of Agreement (MOA) between the Corps and the EPA. This MOA sets forth the sequencing procedures to be followed by the agencies in determining whether a proposal avoids, minimizes, and compensates for impacts to wetlands and other waters of the United States. See Chapter 15 for more information on wetland avoidance, minimization, and compensation strategies and refer to Chapter 31 for detailed permitting information.

Figure 2.3 Broadleaf arrowhead is an obligate wetland species. Wetland surveys consider vegetation, hydrology, and soils in classifying wetlands. (Photo courtesy of Sara Weimer)

National Historic Preservation Act (NHPA; 1966, as amended through 1992)

The NHPA establishes a national policy of preserving, restoring, and maintaining cultural resources. The National Register of Historic Places protects historic properties. Cultural assessments are now part of the formal environmental assessment required under NEPA. New projects are evaluated based on potential effects, positive and negative, to the character, scale, or style of historic buildings and districts. (See Figure 2.4.)

Wild and Scenic Rivers Act (1968, as amended through 1974)

This act establishes the National Wild and Scenic Rivers System for the protection of rivers with important scenic, recreational, fish and wildlife, and other values. The act designates over 130 rivers, with adjacent land, as components of the system. Water resource projects that would have a direct and adverse effect on the values for which a river is designated as an actual or potential system component are prohibited. Rivers are classified as wild, scenic, or recreational and hunting and fishing are permitted in components of the system under applicable federal and state laws.

National Environmental Policy Act (NEPA; 1970)

As well as being the declaration of national environmental policy, NEPA requirements stipulate that actions of federal and *nonfederal agencies* that use federal funds or *require federal approval or permits,* such as an NPDES permit, are subject to an environmental impact review. The specific requirements are covered under 40 CFR 1500 et. seq; environmental review requirements for specific agencies are usually published in separate guidelines that are written to interpret NEPA requirements as they apply to a given agency's activities.

The implementation of NEPA establishes procedures to ensure that appropriate actions are taken to protect, restore, and enhance the environment. NEPA provides a systematic means of dealing with environmental concerns and the associated costs. One of the unique components of NEPA is that it provides a mechanism for public participation. (See Figure 2.5.)

The NEPA process is intended to help public officials make decisions that are based on understanding the environmental consequences associated with a proposed action by a federal agency. This perspective would influence decisions made in land development issues. NEPA requirements are invoked when airports, buildings, military complexes, highways, parkland purchases, and other federal activities are proposed. In addition to government buildings and roads, a major federal action can include private developments in federally protected wetlands or projects on or adjacent to federally controlled property such as limited-access highways or military bases. Actions also include federal funding and federal permitting activities, so that any involvement by the federal government triggers the NEPA process. Many local jurisdictions have similar environmental analysis processes for state, local, and private actions.

Following the requirements of NEPA, prior to implementing a proposed action an environmental review must be performed to identify and address the following:

- Any environmental impacts of the proposed action
- Any adverse environmental effects that cannot be avoided
- Alternatives to the proposed action
- The relationship between local, short-term uses of man's environment and the maintenance and enhancement of long-term productivity
- Any irreversible and irretrievable commitments of resources that would be involved in the proposed action should it be implemented

There are three levels of environmental review: (1) categorical exclusion (CE), (2) environmental assessment (EA), and (3) environmental impact statement (EIS). A full EIS is a major undertaking and requires a significant investment of time and money. Specialists in this field usually perform it. See Chapter 3 for detailed information on preparation of both site assessments and impact statements.

FIGURE 2.4 Ellis Island restoration required cultural and natural resource planning.

Clean Air Act (CAA; 1970, as amended through 1990)

Some of the major factors that contribute to air pollution are urbanization, industrial development, and the increasing use of motor vehicles. Air pollution poses a danger to public health and welfare, including our agricultural crops and livestock. The CAA focuses on the reduction or elimination of the amount of pollutants produced or created. Air quality is an international issue because polluted air can migrate across national borders, impacting the environment and human health throughout the world. Therefore, air quality requires

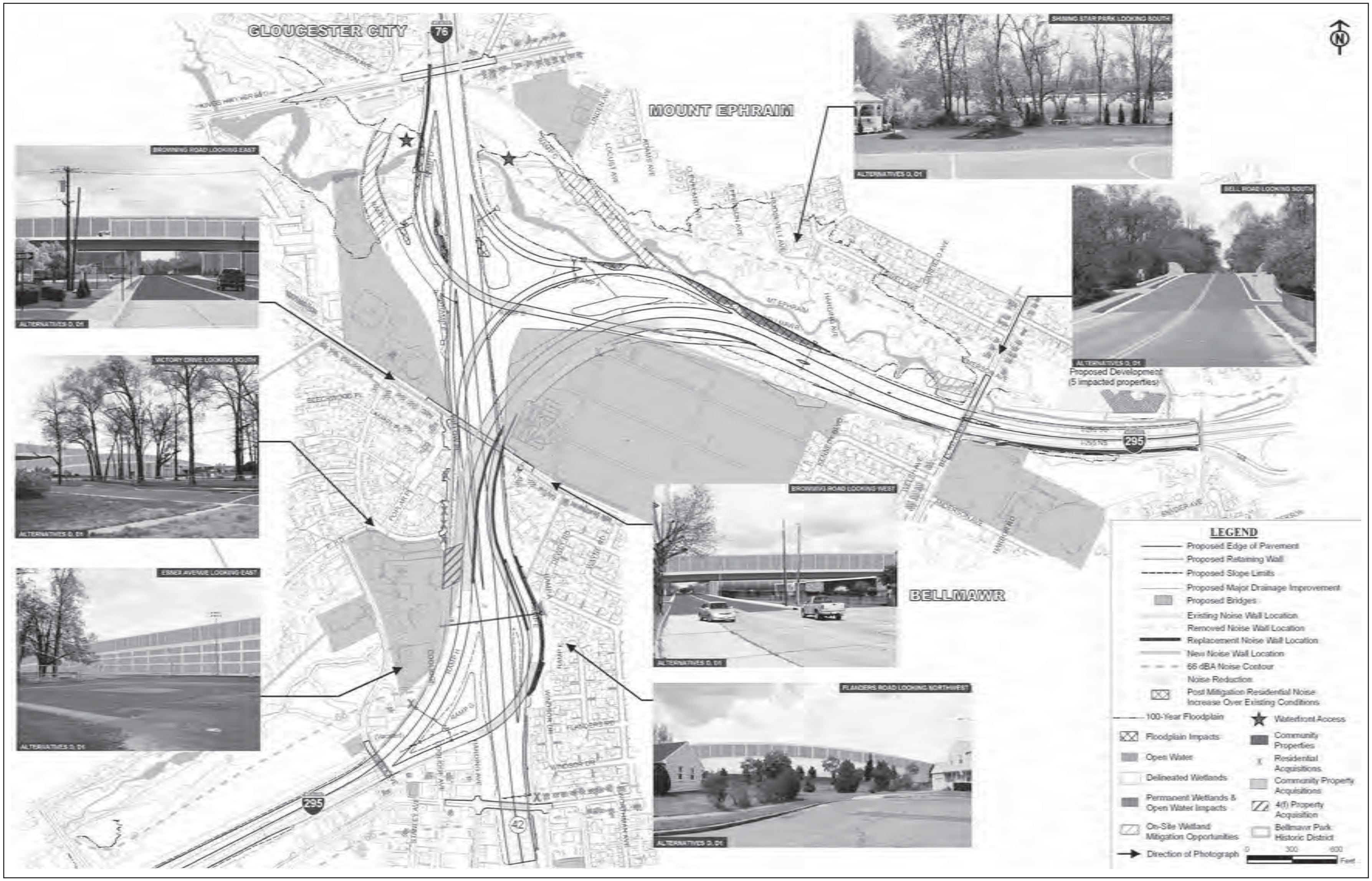

Figure 2.5 GIS and photosimulation are some of the tools used in a NEPA analysis.

participation from all countries. Given the highly diverse economic and political climates of all the countries throughout the world, this issue is extremely challenging to resolve.

A few common air pollutants have been classified as "criteria air pollutants" because the EPA has regulated them by first developing health-based criteria, then setting permissible levels, also called the National Ambient Air Quality Standards (NAAQS). A geographic area that meets or does better than the primary standard (permissible level) is said to be "in attainment"; areas that fail to meet the primary standard are referred to as "non attainment areas."

The law recognizes that states should take the lead in carrying out the CAA, because pollution control problems often require special understanding of local industries, geography, housing patterns, and so on. Therefore, states are required to develop state implementation plans (SIPs) that explain how they will carry out the CAA. A SIP is a collection of the regulations a state uses to clean up polluted areas or otherwise meet the primary standards for criteria pollutants. The states must involve the public, through hearings and opportunities to comment, in the development of each SIP. Legislation and regulations will continue to evolve to address air pollution issues such as global warming, ozone depletion, acid rain, and indoor air quality. In nonattainment areas, developers should be aware of the applicable SIP, as this may require increased mitigation to improve existing conditions including such actions as restrictions on construction equipment and work hours. Some of the issues surrounding air quality are impacts to human health and the effects on the cost to the industries. Air emissions from incinerators and other types of transfer storage and disposal facilities regulated under the RCRA must comply with applicable ambient standard and/or emission limitations of the CAA. Extraction of pollutants from air emissions under CAA controls can create hazardous sludges containing such wastes. Disposal of these materials must comply with the RCRA.

Coastal Zone Management Act (CZMA; 1972, as amended through 1996)

The CZMA is a federal program that establishes standards to protect the coastal resources that are determined to be of national significance. These resources include coastal areas, wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife and their habitat. The act protects these coastal areas by managing development through the creation of *special area management plans* (SAMPs). SAMPs identify specific strategies to protect significant natural resources, promote reasonable coastal-dependent economic growth, and improve protection of life and property in hazardous areas including those areas likely to be affected by land subsidence, sea-level rise, or fluctuating water levels.

Endangered Species Act (1973, as amended through 1988)

The objective of this act is to conserve threatened and endangered species. The Fish and Wildlife Service of the U.S. Department of Interior promulgates a list of threatened and endangered species and their critical habitat. As habitat loss is the primary threat to most imperiled species, the designation of critical habitat zones is essential to effective recovery. While the regulatory aspect of critical habitat does not apply directly to private and other nonfederal landowners, large-scale development on private and state land typically requires a federal permit and thus becomes subject to critical habitat regulations (see Figure 2.6).

Federal agencies are required to carry out programs for the conservation of threatened and endangered species and must take actions to ensure that projects they authorize, fund, or carry out are not likely to jeopardize the existence of the listed species or result in the destruction or modification of their habitat that is declared to be critical.

As of April 3, 2007, 41 species have been delisted; some have been recovered, while nine have been declared extinct. Twenty-three have been downlisted from "endangered" to "threatened" status. (See, for example, Figure 2.6.)

Safe Drinking Water Act (SDWA; 1974, as amended through 1996)

The Safe Drinking Water Act was established to protect the quality of drinking water in the United States. This law focuses on all waters actually or potentially designed for drinking use, whether from surface or ground water sources. The act authorized the EPA to establish safe standards of purity, known as *maximum contaminant levels* (MCLs). State governments, which assume this power from the EPA, also encourage attainment of secondary standards (nuisance-related). The Comprehensive State Ground Water Protection Programs (CSGWPPs) established a partnership between the states, tribal governments, and the EPA to implement EPA's ground water protection goals. A complex act, the SDWA has been amended numerous times, resulting in increasingly stringent drinking water regulations for both municipal and small, localized, on-site drinking water systems. As a result, additional detail is provided on the SDWA in Appendix E.

The SDWA protects the nation's drinking water supply by setting drinking water standards and MCLs and regulating underground injection wells. Both the MCLs and the underground injection control (UIC) program are especially relevant to the RCRA. The MCLs are sometimes used by the RCRA as cleanup standards for corrective actions.

Marine Protection, Research, and Sanctuaries Act (1972, as amended through 1988)

This act regulates the dumping of all types of material into the ocean and designates certain areas of the ocean waters as sanctuaries. The EPA is responsible for issuing permits for the dumping of materials in ocean waters except for dredged material, which is regulated by the U.S. Army Corps of Engineers. The EPA will not issue a permit for the dumping of any radiological, chemical, or biological warfare agents, or high-level radioactive waste.

Figure 2.6 Wild rice survey is performed as part of the site assessment to ensure habitat preservation. Wild rice stands are an essential food source for migratory birds. (Photo courtesy of Sara Weimer)

Toxic Substances Control Act (TSCA; 1976, as amended through 1988)

The TSCA regulates the introduction of new or already existing chemicals. It requires manufacturers to conduct tests on chemicals to determine if they have adverse effects on human health or the environment. The risks to human health include persistence, acute toxicity, and carcinogenic effects. This act authorizes the tracking of more than 75,000 industrial chemicals currently produced or imported into the United States. It controls the disposal methods for certain chemicals such as polychlorinated biphenyls (PCBs). It also authorizes the EPA to impose requirements for asbestos abatement in schools and requires accreditation of persons who inspect for asbestos-containing materials. It requires the EPA to identify sources of lead and to regulate the amount of lead allowed in products.

Resource Conservation and Recovery Act (RCRA; 1976, as amended through 1992)

The primary purpose of the RCRA is to protect human health and the environment from the dangers of hazardous waste. The RCRA regulates the management of hazardous waste, provides technical and financial assistance for the development of management plans, provides facilities for the recovery of energy and other resources from discarded materials, and provides for the safe disposal of discarded materials. The RCRA focuses on the management of wastes from the time they are generated until they are disposed—"from cradle to grave." Unlike CERCLA, the RCRA does not provide for an "innocent landowner" exemption from liability.

Hazardous waste is defined by its characteristics or origin. Wastes that exhibit the characteristics of being ignitable, reactive, corrosive, toxic, or radioactive are considered hazardous. In addition, chemical products involved in a particular waste stream are also considered hazardous. The type or classification of waste is indicated by the use of one or more hazard codes. The hazard codes include ignitable, corrosive, reactive, toxicity characteristic waste, acute hazardous waste, and toxic waste. The chemicals that are involved in these processes are referred to as *listed wastes.* The listed wastes are categorized into four groups, based on the specific process by which they are derived: hazardous waste from nonspecific sources; hazardous waste from specific sources; discarded commercial chemical products, off-specification species, or manufacturing chemical intermediates identified as acute hazardous waste; and discarded commercial chemical products, off-specification species, or manufacturing chemical intermediates identified as hazardous wastes.

Noise Control Act (1972, as amended through 1978)

Noise pollution is a result of human activity and is one of the most pervasive environmental problems. It is not only a public health hazard that causes hearing impairments, but a nuisance that causes psychological stress. The objectives of the Noise Control Act are to establish noise emission standards for new products, utilize noise abatement controls, and label products to increase awareness and protection against individual exposure.

The major sources of community noise are construction and transportation. As development increases, exposure to these noise sources increases. Noise abatement controls can be incorporated into mitigation plans by controlling noise from construction vehicles or by implementing restrictions on time-of-day use. Noise walls are an example of noise control measures related to transportation. Many municipalities have noise ordinances that may vary due to site-specific or regional noise concerns; for example, development in close proximity to airports and military bases may require noise mitigation and/or monitoring.

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA; 1980, as amended through 1986)

The primary purpose of CERCLA is to protect human health and the environment from the dangers of hazardous waste. CERCLA focuses on the response to existing environmental conditions of a property and the liability of the responsible parties. CERCLA created a revolving fund, commonly referred to as the *Superfund,* utilized by the EPA and state and local governments, to investigate and remediate hazardous waste sites that have been listed by the EPA on the National Priorities List (NPL). One of the unique features of CERCLA is that governmental and private parties who are not responsible for the investigation and remediation of a property can perform the work using the Superfund and seek reimbursement from the responsible parties. CERCLA covers all environmental media: air, surface water, groundwater, soil, and sediment, and can apply to any type of facility. If cleanup is conducted on-site under the CERCLA program, no federal, state, or local permit is required.

A CERCLA hazardous substance includes any substance that the EPA has designated for special consideration under the RCRA, CAA, CWA, and TSCA and any substance that presents a substantial danger to human health and the environment. Exclusions from CERCLA's hazardous substance list include petroleum and natural gas and synthetic gas used for fuel. Due diligence and liability assessments fall under CERCLA regulations and amendments and are the most applicable regulations to land development. (See Figure 2.7.) For further discussion, see "Small Business Liability Relief and Brownfields Revitalization Act."

Superfund Amendments and Reauthorization Act (SARA; 1986)

This act is an amendment to CERCLA and provides additional authorization and amendments to CERCLA. SARA establishes requirements for reporting on-site hazardous/toxic materials and/or substances under Title III, the Community-Right-to-Know Act. This act establishes requirements for notification of uncontrolled releases.

Pollution Prevention Act (1990)

The Pollution Prevention Act establishes a national policy for waste management. This includes prevention, recycling, treatment, and disposal of wastes. The objective of this act is

Figure 2.7 Record search and appropriate field sampling are necessary for site classification and developing appropriate redevelopment strategies. (Photo courtesy of Brian A. Sayre)

to prevent or reduce pollution at the source, wherever feasible. Where pollution cannot be prevented, it should be recycled in an environmentally safe manner. In the absence of feasible prevention and recycling options, pollution should be treated to applicable standards prior to release or transfer. Only as a last resort are wastes to be disposed of.

Occupational Safety and Health Act (1970)

As important as the aforementioned acts are in protecting health and the environment, it is equally important to protect the workers who are involved with the mitigation of environmental concerns. The Occupational Safety and Health Act of 1970 (29 U.S.C. 651 et. seq.) contains provisions that protect workers performing environmental cleanups. The federal Occupational Safety and Health Administration (OSHA) is the governing agency for worker protection. It is important that the developer understand the consequences of not adhering to the regulations or performing illegal cleanups using unprotected workers who have not received the proper training and certifications. All contractors performing work for the developer should be thoroughly evaluated to ensure that they, as a matter of business course, always comply and are in full compliance with all environmental and OSHA regulations.

Small Business Liability Relief and Brownfields Revitalization Act (Brownfields Law; 2002)

Brownfields legislation was designed to empower states, communities, and other stakeholders in economic redevelopment to work together in a timely manner to assess, safely clean up, and sustainably reuse brownfield properties. A brownfield is real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant. The result of the cleanup and revitalization of these properties is an increase in local tax bases, facilitation of job growth, utilization of existing infrastructure, preservation of undeveloped open land (greenfields), and improvement and protection of the environment.

EPA's Brownfields Program provides financial and technical assistance for brownfields activities through an approach based on the following four main goals: protecting the environment, promoting partnerships, strengthening the marketplace, and sustaining reuse. Passage of the Brownfields Law amended CERCLA by providing relief for small businesses from liability under CERCLA, while promoting the cleanup and reuse of brownfields through financial assistance and enhancement of state response programs, and for other purposes.

As a result of this amendment, liability relief for small business is achieved and documented via the "all appropriate inquiries" process established and standardized by the EPA. "All appropriate inquiries," also referred to within the industry as "due diligence," is the process of evaluating a property's environmental conditions and assessing potential liability for any contamination utilizing a Phase I Environmental Site Assessment. In 2005, the American Society for Testing and Materials International (ASTM), working with the EPA, issued a revised standard for conducting the due diligence Phase I Environmental Site Assessments (ASTM

E1527-05) in order to demonstrate compliance with this amendment. Phase I Environmental Site Assessments are discussed in detail in Chapter 3.

The EPA has provided the technical tools and resources for states to administer brownfields revitalization programs to promote business and encourage environmental cleanups. Developers benefit from the Brownfields Program by applying their technical and managerial expertise to the entire process of cleaning up and adapting properties for new uses. Developers are an integral part in the success of implementing the brownfields program along with investors; citizens and community groups; and local, county, and state government agencies, including environmental protection/conservation and economic development authorities.

CONCLUSION

From the perspective of the developer and the engineer, environmental regulations impact real estate transactions, demolition, restoration, and development. Therefore, understanding the basis and objectives of environmental issues and integrating appropriate actions in planning and schedules of development projects can prevent unanticipated delays and conflicts. Environmental issues must be proactively addressed and dealt with, often with agencies, procedures, and individuals outside the traditional development process. The earlier in the development process that environmental issues are identified, the better, since some of these issues can involve liability or even affect the purchase or development potential of a property. Other environmental considerations may affect the design and scope of the project, in turn affecting development efficiencies and appropriate use of resources.

ACKNOWLEDGMENT

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National Historic Preservation Act (NHPA)

Noise Control Act

Occupational Safety and Health Act

Pollution Prevention Act

Resource Conservation and Recovery Act (RCRA)

Safe Drinking Water Act (SDWA)

Small Business and Liability Relief and Brownfields Revitalization Act

Superfund Amendments and Reauthorization Act (SARA)

Toxic Substances Control Act (TSCA)

Virginia Administrative Code, 9 VAC 20-60-100

Wild and Scenic Rivers Act

CHAPTER 3

ENVIRONMENTAL SITE FEASIBILITY AND ASSESSMENTS

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INTRODUCTION

The first portion of this chapter discusses various environmental areas that should be considered when evaluating a site for development purposes. This type of evaluation is an important component of the overall site feasibility process because some environmental factors such as existing wetlands or streams, critical habitat for a threatened or endangered species, or the presence of hazardous materials onsite could significantly alter the amount of developable area available on a particular parcel of land or could adversely affect the cost and schedule of a development project. The discussions in this chapter are intended as an overview to familiarize developers and their land development professionals with the environmental issues related to land development projects. Because of the complex nature of environmental issues and regulations, it is advisable to retain an environmental professional to complete the environmental portion of a site feasibility review.

The second portion of this chapter provides an overview of the different types of environmental studies and documentation that may be required as part of the land development process, focusing specifically on the environmental site assessment (ESA) and the environmental assessment (EA) processes. Phase I ESAs are typically required under the provisions of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to assess the potential presence of recognized environmental conditions (RECs) at a site. Phase II and III ESAs evaluate the presence, type, level, and extent of contamination at the site and any necessary remedial actions required. EAs, typically performed pursuant to the requirements of the National Environmental Policy Act (NEPA), are used to analyze the potential impacts of a proposed action on the natural and human environment of a site. A developer is most likely to be faced with the requirement of performing an ESA; therefore, for the purposes of this chapter, the ESA process is described in more detail than the NEPA EA process.

ENVIRONMENTAL SITE FEASIBILITY

When determining the development potential of a particular piece of land, the developer should first evaluate the land's opportunities and constraints, both of which may be related to environmental issues. Therefore, a preliminary environmental review of a site should be completed in the early feasibility assessment stages of the land development process. This review is typically a two-step approach:

1. Perform an office or desktop data review to identify environmental considerations that may warrant closer field inspection. This review includes a cursory investigation of available wetland, hazardous material, endangered species, and cultural resources data for the site.

2. Complete a site visit or walkover to confirm the information garnered in the desktop review and ensure that current conditions (which may not be entirely or accurately reflected in the desktop review) are identified and assessed.

Note that these reviews are preliminary and for planning purposes only. They are intended to help the design team identify any red flags inherent to the site itself that might prohibit or substantially derail (because of either time or cost) a proposed development project. Early identification of environmental site conditions can significantly enhance programming, planning, and design and even construction efforts as well as facilitate realistic project scheduling. Additional investigations will likely be required, depending on the existing features.

Preliminary Wetland Assessment

Wetland Data Review. The wetland data review consists of researching existing information concerning the site. Typically, this process begins with a desktop evaluation of available information. At a minimum, an office investigation should be undertaken to determine the likelihood of the presence of waters of the United States or wetlands on the site.

Examples of readily available information are discussed in the following subsections. However, note that these resources are mass-produced at a small scale and frequently are outdated or have omissions or incomplete data. Therefore, a desktop review of wetland data should not be considered sufficient to exclude the presence of wetlands or waters of the United States on a site.

U.S. Geological Survey (USGS) 7.5-Minute Topographic Series Maps. These maps, which are also known as *topographic quadrangles,* can be obtained directly from the U.S. Geological Survey. In addition, various websites also offer topographic maps. Typically, there is a fee associated with downloading a map from these websites. These maps can identify such features as marshes, lakes, ponds, rivers, streams, and other water bodies that might be present on the site. In addition, these maps can be used to determine drainage swales or low-lying areas that may exhibit wetland characteristics and should be evaluated during the wetland walkover. These maps are available in scales up to 1:24,000.

Wetlands Mapping. Much of the United States has been mapped by the U.S. Fish and Wildlife Service (FWS) National Wetland Inventory (NWI). These maps are available on the FWS Wetland Mapper home page (http://wetlandsfws.er.usgs.gov). The NWI map is prepared from aerial photos, and wetlands are designated according to the FWS's *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin, et al., 1979). If the NWI map indicates wetlands on the site, there is a high probability (greater than 90 percent) that they are jurisdictional wetlands. State and local wetland programs may have created wetlands mapping that includes the site area. If available, these maps can typically be found on the county or state GIS webpage.

Natural Resources Conservation Service (NRCS) County Soil Surveys. The U.S. Department of Agriculture, through the NRCS provides soil information for most jurisdictions online via the Web Soil Survey (http://websoilsurvey.nrcs.usda.gov/app/). If there are hydric soil map units or any soil map units with hydric soil inclusions indicated, then one can assume that these areas are potential wetlands and should be field-verified. Confidence in that determination is strengthened if the NWI map also shows wetland in this area. If no hydric soils or hydric soil inclusions are indicated in the study area, it likely lacks the required soil to meet the wetland criteria. However, the site should be field-checked with a quick walkover for verification purposes because soil conditions can change. Development around a site can potentially affect the site hydrology.

Aerial Photographs Review. Aerial photographs can provide information on vegetation and hydrology and should be consulted as part of a wetland data review. Many providers on the Internet make aerial photographs available; for example, the USGS TerraServer USA webpage provides aerial photograph coverage for much of the nation. Other possible sources for aerial photographs are county or city mapping or planning offices, the U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service (ASCS), and NRCS offices located in each county. Numerous counties also have recent aerial photographs available on the county's GIS webpage.

Many counties, especially those with growing populations, regularly commission aerial photo surveys to update county land use mapping. Color infrared (CIR) photography is the most useful when identifying wetland areas from the desktop with aerial photographs, as it can highlight differences in vegetation and soil moisture. The county ASCS office may have CIR photos available for the farmed portion of a county. These are used to determine farm subsidies and to enforce the Swampbuster provisions of the Farm Bills, and they can assist in the desktop wetland review.

In addition, local governments obtain aerial photos to create topographic maps or to update older land use mapping. Typically, these photos are either black-and-white or true color. Similar photos, possibly at a larger scale, may be available for the site if it has been photographed for the development of detailed topographic mapping.

Preliminary On-Site Wetlands Investigation. A preliminary wetland investigation (or wetland walkover) starts when the desktop review is completed. The purpose of the wetland walkover is to verify the information gathered during the desktop review and more accurately identify and roughly delineate wetlands or waters of the United States on the site. The preliminary field investigation should focus on areas mapped with hydric soils, hydric soil inclusions, and/or mapped as wetland on NWI maps. All of the drainage swales and low-lying areas should also be visited to identify any and all wetlands and identify the stream channels that qualify as waters of the United States.

Ideally, the field study should be done by a team of at least two individuals familiar with the soils, vegetation, and hydrologic indicators in the region. Wetland boundaries should be field-sketched onto the best available topographic mapping. Field notes and/or wetland data sheets should record the hydrologic conditions, soil characteristics, and dominant vegetation in each of the wetland types encountered. Notes on the rationale behind the preliminary boundary delineation should be made, including characteristics of the upland areas at the wetland/upland boundary. Some surveyor's flagging might be tied to vegetation or wire flags placed in the ground to roughly delineate the wetland boundary for later capture by field survey. The wetland walkover results in identifying general areas on-site that should be avoided by development, if possible.

If it is determined during the wetland walkover that potential jurisdictional areas are located on-site, then a formal wetland delineation would be required. The formal wetland delineation process is fully discussed in Chapter 15.

Threatened and Endangered Species Habitat Review

As discussed in Chapter 2, habitat loss is the primary threat to most imperiled species, and critical habitat zones are essential in protecting threatened or endangered species. While the regulatory aspect of critical habitat under the Endangered Species Act does not apply directly to private and other nonfederal landowners, large-scale development on private and state land typically requires a federal permit for either stormwater discharges (NPDES) or impacts to wetlands or waters of the United States, and thus becomes subject to critical habitat regulations. Federal permitting agencies are required to coordinate with the U.S. Fish and Wildlife Service to ensure that projects they authorize are not likely to jeopardize the existence of the listed species or result in the destruction or modification of their habitat that is declared to be critical.

As a result of this requirement, it is advisable to complete a review of any potential development site to determine whether there is a likelihood of impacting a threatened or endangered species or their habitat as a result of the land development process. This review can be accomplished by contacting either the FWS or the state equivalent. Some states have this information available via a website.

Cultural Resources Assessment

As discussed in Chapter 2, the National Historic Preservation Act establishes a national policy of preserving, restoring, and maintaining cultural resources. Similar to the Endangered Species Act, federal permitting agencies are required to coordinate with the State Historic Preservation Office (SHPO) to ensure that the projects they authorize are not likely to jeopardize existing cultural resources. As a result of this requirement, it is advisable to complete a review of any site considered for development to determine whether there is a potential to impact cultural resources listed or eligible for listing on the state or National Register of Historic Places as a result of the land development process. This review can be accomplished by contacting the SHPO and, in most jurisdictions, by consulting the comprehensive plan. Some states may have this information available via a website.

Regulatory Database Review: Contamination Investigation

Contaminated sites may exist as a result of past or present land use activities. Environmental regulations, as described in Chapter 2, require the assessment of the type and extent of contamination potentially present at a site as well as the development of adequate remediation measures to address the contamination identified. *Hazardous waste* refers generally to discarded waste materials from institutions, commercial establishments, and residences that pose an unacceptable risk to human health and safety, property values, and the environment. Typical sources of contamination include surface impoundments, landfills, spills, tanks, septic tanks, agriculture, urban runoff, deep well injection, and illegal dumping.

Information about potential contamination affecting a site can be gathered from state and county environmental offices. In addition, the U.S. Environmental Protection Agency (EPA) has a website called Enforcement and Compliance History Online (ECHO) that also provides information related to compliance, violations, and enforcement actions (http://www.epa-echo.gov/echo/). A comprehensive regulatory database review report can be purchased from several companies that maintain updated regulatory databases. Should the database review indicate possible sources or the presence of contamination, it is important to properly prepare for the site reconnaissance by taking the necessary safety precautions to protect field personnel.

The regulatory database review and site reconnaissance provide a preliminary understanding of potential contamination presence at a given site and surrounding properties and help determine whether additional detailed investigations are warranted.

Natural Hazard and Risk Assessment

Several natural hazards could be associated with a project depending on the geographic location of the site. Possible natural hazards include flooding, wildfires, landslides, earthquakes, hurricanes, erosion, tornadoes, tsunamis, typhoons, droughts, volcanic eruptions, and other severe events related specifically to the geology or climate of a particular site. Additional information about these hazards can be found on the Federal Emergency Management Agency (FEMA) website at http://www.fema.gov/ or by contacting the local FEMA office (see contact information in Chapter 18).

Although natural hazards are relatively unpredictable, risk assessment at the early stages of a project can result in more informed and responsive site selection, planning, engineering, architectural, and other design-related decisions. Specific design strategies can be utilized during the development process to attempt to mitigate natural hazards, thereby preventing natural disasters at a given site. Simple measures, such as two means of ingress/egress from a development, reasonable shoreline setbacks for coastal development, adequate communications infrastructure, appropriate material selections for buildings and infrastructure, and code-compliant construction, can greatly enhance the built environment's response to natural hazards and the protection of communities in terms of both population and property loss.

Site Walkover/Reconnaissance

Once a desktop review has been completed, it is advisable that a site walkover/site reconnaissance be conducted to ground-check the desktop data collected. This can be done in conjunction with the wetland walkover; however, because of the various disciplines involved, it may be necessary to have more than one specialist visit the site. Government databases may be outdated and therefore inaccurate. During the site visit, observations should be recorded in a field notebook and existing conditions should be photodocumented. Observations should be made of the presence of natural site features, the nature of development (i.e., industrial, commercial, residential), the potential presence of old or architecturally distinctive standing structures, and the presence of potential sources of contamination on-site and on the adjacent properties. Data gathered during the site visit should be shared with all team members working on the project.

Some of the items to note during the site walkover are these:

- Streams, swales, drainages, and low-lying or wet areas
- Existing buildings or structures—condition, approximate age, and composition (potential source of asbestos-containing material and/or lead-based paint)
- Outbuildings and storage areas, noting any hazardous materials signs (pesticides, herbicides, paints, and solvents are often stored in these locations)
- Existing utilities—electric, water, gas, sewer, stormwater, water wells, or septic systems
- Underground and aboveground storage tanks (vent pipes and fill ports are indicators of underground storage tanks)
- Ground water monitoring wells
- Soil or vegetation staining or discoloration
- Stressed vegetation
- Large (specimen) trees and the approximate percentage of forest cover
- Old or architecturally distinctive standing structures
- Potential wildlife habitat/corridors

If items such as these are identified on-site, additional research should be conducted to assess whether these conditions impact the amount of developable area and identify the type of site design accommodations that might be required to avoid or minimize impacts or the mitigation measures that are available to address unavoidable impact. Depending on the initial findings during the site walkover, a more formal environmental assessment or study may be warranted.

ENVIRONMENTAL ASSESSMENTS UNDER CERCLA AND NEPA

The terms *environmental site assessment* (ESA) and *environmental assessment* (EA) are used to describe specific types of environmental documents necessary to meet applicable regulatory requirements. Despite their similarity in title, the objectives and purposes of these two studies are quite different.

In simple terms, the ESA is performed as a due diligence effort prior to a real estate transaction to document existing, recognized environmental conditions (RECs) associated with the presence (or likely presence) of hazardous substances (as defined under CERCLA) or petroleum products on the subject property and to allow the user to satisfy one of the requirements to qualify for the innocent landowner defense to CERCLA liability.

The EA called for pursuant to NEPA requirements involves the environmental review necessary to define and evaluate the possible effects of the proposed project on the natural and human environment. Specifically, the EA must consider the environmental consequences of a proposed action and must evaluate a range of alternatives to the proposed action, including the no-action alternative and any available alternatives that avoid or minimize potential environmental impacts. Additionally, the EA must recommend mitigation approaches to address any adverse environmental effects that cannot be avoided should the action be implemented.

Environmental Site Assessment (ESA) under CERCLA—Due Diligence

The ESA is an integral part of the site feasibility effort and is critical in minimizing a developer's environmental liability exposure. The ESA focuses on performing "all appropriate inquiry into the previous ownership and uses" (ASTM E-1527-05) of a specific site with the objective of identifying the RECs present at the site at the time of a real estate transfer or financial transaction related to the real property in question. Currently, the standard of care in the industry is the American Society for Testing and Materials (ASTM) Standard E 1527—2005 (Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process). In accordance with this standard practice, the Phase I ESA is generally intended "to permit a user to satisfy one of the requirements to qualify for the innocent landowner, contiguous property owner, or bona fide prospective purchaser limitations on CERCLA liability." Other federal, state, and local environmental laws may impose environmental assessment obligations that are beyond the scope of a Phase I ESA. In addition, there are likely to be other legal obligations concerning hazardous substances or petroleum products discovered on a property that are not addressed in this practice and may pose risks of civil and/or criminal sanctions for noncompliance. There are many assessments that are called ESAs with different scopes of work.

Due to the impacts on the environment, federal and state governments have enacted legislation requiring the cleanup of conditions that pose a risk or threat of risk to human health or the environment. These laws have been promulgated to prosecute any party deemed to be a potentially responsible party (PRP). This has far-reaching implications, as the definition of a PRP is not limited to those parties responsible for the actual contamination, but also applies to owners, past, present, or subsequent; lessors; managers; lienholders; transporters; and other parties having ownership or management responsibility. Furthermore, there is no standard rule for assigning responsibility for a liability.

As stated, the objective of a Phase I ESA is to identify, to the extent feasible, RECs in connection with a property. A recognized environmental condition, as defined by the ASTM, indicates "the presence or likely presence of any hazardous substances or petroleum products on a property under conditions that indicate an existing release, a past release, or a material threat of release of any hazardous substances or petroleum products into structures on the property, or into the ground, ground water, or surface water of the property" (ASTM E-1527-05). The term is not intended to include conditions that generally do not present a material risk of harm to human health or the environment and that would not be the subject of an enforcement action if they were brought to the attention of the appropriate governmental agencies.

Phase I ESAs, which are typically performed as part of commercial real estate transactions, are very common and are usually required by lending institutions prior to the acquisition of a property. Phase I ESAs should be performed very early in the development planning stage to avoid stoppage of work or delays associated with environmental conditions at the property. Once a property is identified as one for which a Phase I ESA is being considered or is required, certain information, as recommended in the ASTM User Questionnaire (Figure 3.1), should be collected, if available, prior to the selection of an environmental professional. This information should be provided to the environmental professional selected to conduct the Phase I ESA.

Environmental professionals with the proper training and experience per the ASTM standard are required to perform these assessments in order for the developer/owner to qualify for liability protection. The ASTM provides guidance to assist users in the preparation for and selection of an environmental professional to conduct a Phase I ESA. The technical competence of the environmental professional and the firm's quality assurance/quality control program, internal risk management program, experience, standard terms and conditions, and errors and omissions liability insurance policy should be evaluated prior to retaining the professional who will provide these services.

A Phase I ESA has four components: records review, site reconnaissance, interviews, and report preparation. The record review is performed to obtain and review records to help identify RECs in connection with the property. This includes review of records related to property ownership and the use of hazardous substances and petroleum products onsite as well as on areas outside the property that are likely to migrate onto the property. The information for the record research is typically obtained through a variety of public and other database sources, as discussed earlier. The site reconnaissance is performed to visually and physically observe the site and adjoining properties for evidence of RECs. If the property has buildings or structures, the interior of the buildings should also be observed and documented. The interviews conducted as part of the assessment are performed to gather information about the property from those who are most familiar with the current and past uses of the property. Finally, the Phase I ESA report is prepared to document the work performed, findings, opinions, and conclusions. Figure 3.2 shows the report format recommended by ASTM. Figure 3.3 shows typical features identified in a Phase I ESA.

The typical Phase I environmental assessment (ESA) usually does not include performing environmental testing or evaluations for the following considerations unless specifically requested by the intended user or organization paying for the assessment:

- Asbestos
- Lead-based paint
- Lead in drinking water
- Radon
- Wetlands

As the laws regarding legal responsibility for environmental contamination have had insufficient time for legal precedents, limited safety is available to a buyer, lender, or insurer. In addition, there are no standards, beyond the guidelines outlined by ASTM E1527, or absolutes for environmental inspections (assessments). Technical guidelines exist on how to perform certain investigative actions; however, no approved or standard level of investigation has been required, codified, or adopted in a legal sense. Consequently, there is no numerical definition of what is legally considered an acceptable level of environmental risk; there are only comparative standards (drinking water standards, risk-based concentration calculations, etc.).

The general cost of a typical Phase I ESA for a parcel of commercial real estate ranges from $2500 to $3500 depending on size, location, and type of property. Industrial properties and large parcels of land with numerous RECs and a long history of industrial use could cost significantly more than the typical ESA. A third party, composed of qualified professionals per the ASTM standard, should perform these assessments. Oftentimes, lending institutions have lists of approved professionals who perform this work. In addition, regulators may also maintain a list of qualified professionals. Although an ESA can be technical, a purchaser, developer, and/or lender should be familiar with the evaluation's findings and conclusions. The ESA report should be kept on record, since it is the proof that a due diligence study was performed to determine the status of the property.

If environmental concerns are identified in the initial ESA, they are likely to require further investigation. This further investigation is typically referred to as a Phase II ESA. Varieties of environmental testing methods exist that can be used to analyze for the wide variety of contaminants, as required under specific regulations. Since each potentially contaminated property is unique, a detailed site-specific environmental sampling and analysis plan should be developed for each property. For more information on the ASTM environmental site assessment process, visit their website at www.astm.org.

Phase II ESA. A Phase II ESA is performed to further investigate the potential presence of a suspected contaminant or to assess whether a release of a contaminant or regulated substance that occurred on the property might have adversely impacted the site soil, ground water, and/or surface water. Additionally, a Phase II ESA may be required in situations other than real estate transactions. For example, if an existing property owner has experienced a known release of a contaminant or regulated substance, he or she is responsible for the release and must take corrective action to assess and mitigate the situation, as necessary.

Unlike the prescribed scope and relatively low cost of a Phase I ESA, the scope for a Phase II ESA is highly unpredictable based on the variety of scenarios associated with the release of a contaminant. For example, a Phase II ESA might require only a few samples to be collected from the soil surface to assess the presence, type, and level of contamination associated with a localized petroleum product

X3. USER QUESTIONNAIRE
INTRODUCTION

In order to qualify for one of the *Landowner Liability Protections (LLPs)*[35] offered by the Small Business Liability Relief and Brownfields Revitalization Act of 2001 (the "*Brownfields Amendments*"),[36] the *user* must provide the following information (if available) to the *environmental professional.* Failure to provide this information could result in a determination that "*all appropriate inquiry*" is not complete.

(1.) Environmental cleanup liens that are filed or recorded against the site (40 CFR 312.25).
Are you aware of any environmental cleanup liens against the property that are filed or recorded under federal, tribal, state or local law?

(2.) Activity and land use limitations that are in place on the site or that have been filed or recorded in a registry (40 CFR 312.26).
Are you aware of any AULs, such as *engineering controls,* land use restrictions, or *institutional controls* that are in place at the site and/or have been filed or recorded in a registry under federal, tribal, state, or local law?

(3.) Specialized knowledge or experience of the person seeking to qualify for the LLP (40 CFR 312.28).
As the *user* of this *ESA* do you have any specialized knowledge or experience related to the *property* or nearby properties? For example, are you involved in the same line of business as the current or former *occupants* of the *property* or an adjoining *property* so that you would have specialized knowledge of the chemicals and processes used by this type of business?

(4.) Relationship of the purchase price to the fair market value of the *property* if it were not contaminated (40 CFR 312.29).
Does the purchase price being paid for this *property* reasonably reflect the fair market value of the *property*? If you conclude that there is a difference, have you considered whether the lower purchase price is because contamination is known or believed to be present at the *property*?

(5.) Commonly known or reasonably *ascertainable* information about the *property* (40 CFR 312.30).
Are you aware of commonly known or *reasonably ascertainable* information about the *property* that would help the *environmental professional* to identify conditions indicative of releases or threatened releases? For example, as *user,*
(a.) Do you know the past uses of the *property*?
(b.) Do you know of specific chemicals that are present or once were present at the *property*?
(c.) Do you know of spills or other chemical releases that have taken place at the *property*?
(d.) Do you know of any environmental cleanups that have taken place at the *property*?

(6.) The degree of obviousness of the presence or likely presence of contamination at the *property,* and the ability to detect the contamination by appropriate investigation (40 CFR 312.31).
As the *user* of this *ESA,* based on your knowledge and experience related to the *property* are there any *obvious* indicators that point to the presence or likely presence of contamination at the *property*?

[35]*Landowner Liability Protections,* or *LLPs,* is the term used to describe the three types of potential defenses to Superfund liability in EPA's *Interim Guidance Regarding Criteria Landowners Must Meet in Order to Qualify for Bona Fide Prospective Purchaser, Contiguous Property Owner, or Innocent Landowner Limitations on CERCLA Liability* ("*Common Elements*" Guide) issued on March 6, 2003.
[36]P.L. 107-118.

FIGURE 3.1 ASTM User Questionnaire for Phase I ESAs. (Copyright ASTM International. Reprinted with permission from ASTM E1527-05) spill at a specific location. On the other hand, a hazardous waste may have been released with potential impacts to the ground water, air, and/or surface water, requiring an extensive sampling approach, including the installation of soil borings and ground water monitoring wells, the collection of surface water and/or sediment samples, and the performance in some jurisdictions of a baseline environmental evaluation (BEE).

The purpose of a Phase II ESA is to assess the presence, type, and level of contamination at a site. This generally requires environmental sampling. The protocol for collecting and analyzing environmental samples is based on the suspected contamination, the media, data quality objectives, and the regulatory program requiring the site assessment. The Phase II ESA report summarizes the investigation performed, provides a description of the sampling and analysis program (including sampling procedures and methodologies, sampling locations and rationale, analytical parameters, and methodologies), and reports the analytical results. If the presence of contamination is confirmed, the report provides recommendations for any further actions.

The time frame and cost of Phase II ESAs range considerably from a few thousand dollars and a one-month turnaround time to tens of thousands of dollars and more than a one-year time frame. In fact, extreme cases could cost millions of dollars to investigate over a period of several years.

1. Summary

2. Introduction
2.1 Purpose
2.2 Detailed Scope-of-Services
2.3 Significant Assumptions
2.4 Limitations and Exceptions
2.5 Special Terms and Conditions
2.6 User Reliance

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3.1 Location and Legal Description
3.2 Site and Vicinity General Characteristics
3.3 Current Use of the *Property*
3.4 Descriptions of Structures, Roads, Other Improvements on the Site (including heating/cooling system, sewage disposal, source of potable water)
3.5 Current Uses of the Adjoining Properties

4. User-Provided Information
4.1 Title Records
4.2 Environmental Liens or Activity and Use Limitations
4.3 Specialized Knowledge
4.4 Commonly Known or Reasonably Ascertainable Information
4.5 Valuation Reduction for Environmental Issues
4.6 Owner, Property Manager, and Occupant Information
4.7 Reason for Performing *Phase I*
4.8 Other

5. Records Review
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5.2 Additional Environmental Record Sources
5.3 Physical Setting Source(s)
5.4 Historical Use Information on the Property
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6.1 Methodology and Limiting Conditions
6.2 General Site Setting
6.3 Exterior Observations
6.4 Interior Observations

7. Interviews
7.1 Interview with Owner
7.2 Interview with Site Manager
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7.4 Interviews with Local Government Officials
7.5 Interviews with Others

8. Findings

9. Opinion

10. Conclusions

11. Deviations

12. Additional Services

13. References

14. Signature(s) of Environmental Professional(s)

15. Qualification(s) of Environmental Professional(s)

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16.5 Regulatory Records Documentation
16.6 Interview Documentation
16.7 Special Contractual Conditions between User and Environmental Professional
16.8 Qualification(s) of the Environmental Professional(s)

FIGURE 3.2 Recommended outline for a typical Phase I ESA from ASTM E1527-05. (Copyright ASTM International. Reprinted with permission from ASTM E1527-05)

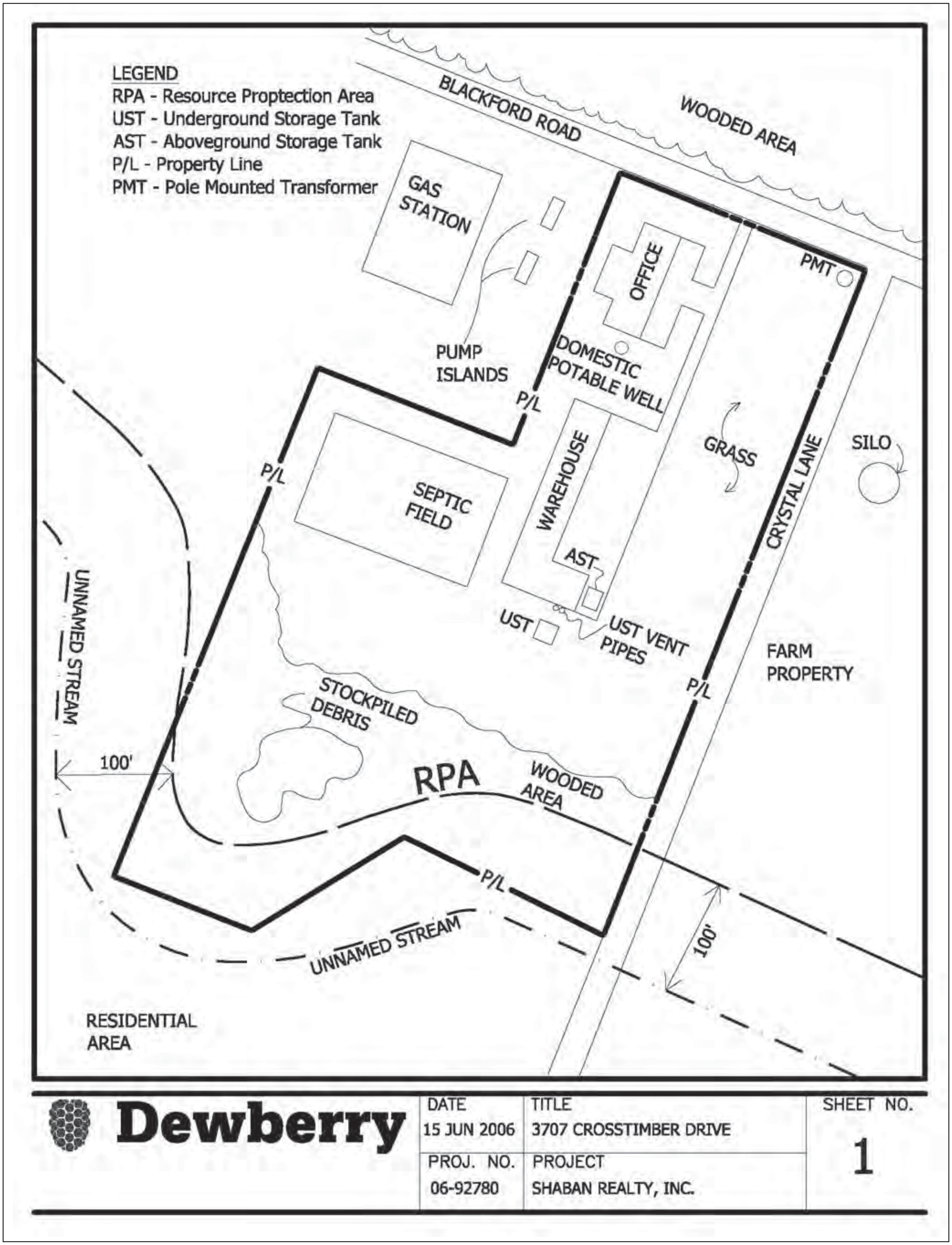

FIGURE 3.3 Typical site plan showing key site features and recognized environmental conditions at and adjacent to site.

If an environmental testing program is warranted, there are limitations and risks associated with environmental testing that all involved parties must be aware of. In fact, if testing, completed as part of a Phase II ESA, detects contamination, the results of the testing have to be reported to federal, state, and/or local agencies. On the other hand, inadequate studies and testing can expose all of the involved parties to legal liability due to negligence.

The main objective of a Phase II ESA is to determine whether the suspect contamination is present on the property and, if so, to what extent. The type(s) and amount of contaminant(s), as well as the property location/site characteristics, all play a role in determining the scope of work for the Phase II ESA.

Phase III ESA. Typically, a Phase III ESA is the most expensive phase of environmental site assessments. Once a REC is identified (Phase I) and suspected to be significant enough to require further investigation (Phase II), a Phase III ESA is performed to determine the extent of contamination and, if required, available remediation alternatives. In some cases where remediation is required, the Phase II and Phase III ESAs may be blended. The cost and time frame to remediate a site can range from tens of thousands of dollars over several months to several million dollars over several years. The factors that influence cost and time include the type of contaminant, quantity of the release, the media that is impacted, and the location of the release. Because of the high variability of scenarios for Phase III ESAs, they are typically handled on a case-by-case basis.

Additional discussion related to the development of a contaminated site can be found in Chapter 17.

NEPA Environmental Assessment (EA)

The National Environmental Policy Act (42 U.S.C. 4321 et seq.) requires an environmental evaluation of major federal actions that could significantly affect environmental quality. One of the primary goals of NEPA is to take potential environmental impacts into consideration early on during the decision-making process. While these evaluations are most commonly encountered with federally sponsored projects, privately funded or other nonfederally sponsored projects can be required to undergo the NEPA evaluation process when some form of federal involvement is initiated. For example, the granting of a wetland permit by the U.S. Army Corps of Engineers could be the federal action that has a significant effect on environmental quality and thus triggers the NEPA process. Another example is a project that utilizes federal funding in some way such as U.S. Department of Housing and Urban Development funds to provide affordable dwelling units.

In addition to the federally sponsored projects that must undergo the NEPA evaluation process, many states and local agencies have adopted regulations that require an environmental assessment as part of the project authorization or local approval process. Often, these assessments are patterned after the NEPA requirements and involve an evaluation of the existing environmental conditions, potential project impacts, and alternatives considered, as well as ways to mitigate unavoidable project impacts.

Section 15.02(d) of the NEPA regulations requires agencies to provide for the early application of NEPA to cases where actions are planned by private applications or nonfederal entities and are, at some stage, subject to federal approval of permits, loans, loan guarantees, insurance, or other actions. This is intended to ensure that environmental factors are considered at an early stage in the planning process to avoid the situation where the applicant for a federal permit or approval has completed planning and eliminated all alternatives to the proposed action by the time the NEPA process commences or before the NEPA process has been completed. NEPA requires that federal agencies include in their decision-making processes appropriate and careful consideration of all environmental effects of proposed actions and their alternatives for public understanding and scrutiny, avoid or minimize adverse effects of proposed actions, and restore and enhance environmental quality as much as possible.

As part of the evaluation process, the federal or state agency determines the level of NEPA documentation that will be required. There are three types of NEPA documentation: categorical exclusion (CatEx), an environmental assessment (EA), and an environmental impact statement (EIS). The categorical exclusion documentation involves the most streamlined process and can be used on specific types of projects that have been determined to have minimal adverse effect. Many federal agencies have developed a list of categorical exclusions specific to the types of projects that the agency completes on a routine basis.

The environmental assessment is a more complicated process then the CatEx process, as it involves requesting comments from numerous federal, state, and local agencies and it is subject to the public review process. Typically, data collection for an EA includes but is not limited to the following areas: traffic, air quality, noise, contamination, socioeconomics, natural ecosystems, hydraulics and hydrology, and cultural resources.

The EA is prepared to provide sufficient data and analysis to determine whether there is a finding of no significant impact (FONSI) or whether an EIS is required. The EA is a public document that has three defined functions:

1. Briefly provide sufficient evidence and analysis for determining whether to prepare an EIS.
2. Help identify better alternatives and mitigation measures when an EIS is not required.
3. Facilitate the preparation of an EIS when one is required.

The EA typically contains a brief discussion of the need for the proposed action, alternative actions, and the environmental impacts of the proposed actions and alternatives. An

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FIGURE 3.4 Typical format for an environmental assessment under NEPA.

example format for a typical EA under NEPA is provided in Figure 3.4. An environmental review process is implemented to ensure that NEPA considerations are taken into account. This review is the process that determines whether a proposed action might have a significant impact on the environment and therefore require the preparation of an EIS.

In addition, during the initial NEPA evaluation process, a project might be found to have a high potential for significant environmental impacts and, therefore, be required to proceed directly to the preparation of an EIS. An EIS document is a more lengthy and detailed report. Where an EA document can be completed, typically, within 12 to 18 months, an EIS typically takes years to collect all the data, perform the required impact analysis, develop the necessary mitigation recommendations, solicit public comment through very intense public outreach, and reach the conclusion of the process, which is a record of decision.

The EIS requires the evaluation of all reasonable alternatives to determine the impacts the proposed action would have on the human and natural environment. These alternatives must be rigorously explored and objectively evaluated. Where reasonable alternatives are infinite, a reasonable number of alternatives are required to cover the full spectrum of alternatives. In addition, the analysis of the No-action alternative is required to provide a benchmark, enabling decision makers to compare the magnitude of environmental effects with respect to each of the action alternatives. This can be a critical element in the decision-making process to select the preferred alternative because typically there are impacts with the no-action alternative. For example, if the proposed action was to construct mass transit because of the increased traffic in the specified area, the impacts associated with the no-action alternative are the increases in traffic congestion and air pollution. The objective of the EIS is to develop the data necessary to reach a conclusion with respect to the preferred alternative for the implementation of the proposed action. The preferred alternative is the alternative that best meets the purpose and need of a project with the least amount of environmental impacts. At the completion of the EIS, a *record of decision* is generated that documents the selection of the preferred alternative and the environmental commitments made during the EIS process.

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CHAPTER 4

HISTORIC ARCHITECTURAL AND ARCHAEOLOGICAL RESOURCE ASSESSMENT

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INTRODUCTION

The assessment of historic properties is an integral part of the land development process. Historic properties include both historic architectural and archaeological resources. Land development by its nature is the creation of *places,* each of which has the opportunity to establish history. With this understanding, each *developer* (owner, planner, and/or representative) bears the responsibility to respect the past and to plan for the future.

Preserving the artifacts of our history is a reasonable response from a culture that aches for a sense of continuity while living amid constant physical change. Many people and communities feel a decline in continuity as they witness the physical landscape change daily. Steady and rapid change, be it building construction, increased vehicular traffic, and/or cultural integration, contribute to the psychological need people feel to live with a sense of place.

The information in this section is organized to broaden the understanding of historic preservation within the framework of ongoing land development and societal change. In order to appreciate the importance of preserving our past, this chapter begins with an overview of the historic preservation movement in our nation. The sections that follow provide a discussion of the basic steps involved in the assessment of historic properties.

THE HISTORIC PRESERVATION MOVEMENT

The historic preservation movement started with the concerns and actions of private individuals. It has subsequently been institutionalized and has evolved into professional opportunities for a diverse range of disciplines, including architects, historians, architectural historians, landscape architects, lawyers, engineers, photographers, archaeologists, planners, land surveyors, and educators. Several factors have nurtured the increasing professional pursuit of historic preservation within the purview of land development activity:

- *Patriotism:* Our communal and individual need to protect and acknowledge the accomplishments of our national heritage.
- *Due process—representation:* Legislative actions at all levels of government have legitimized a public mandate for preservation activity.
- *Roots:* Our personal need as individuals and professionals to recognize and save artifacts commemorating our heritage.
- *Media:* Attention to lost cultural and historic artifacts has fostered community awareness and education in the field of preservation.
- *Economics:* Reinvestment in historic properties has become financially beneficial due to tax incentives and grant programs.
- *Green design:* The interest in sustainable design has led many professionals to realize the benefits of adaptive reuse and rehabilitation of historic properties in lieu of demolition and new construction.
- *Technology:* The technological advancements and significant changes that our society has experienced in the past decade have led to more reflection and nostalgia about slower times and a longing for the past. Innova-

tions in technology and new approaches to rehabilitation techniques have also encouraged adaptive reuse of historic properties.

The place of origin of the historic preservation movement is reputed to be Fairfax County, Virginia. It began in 1858, when the Mount Vernon Ladies' Association succeeded in saving Mount Vernon, the plantation home of President George Washington (1754–1799). (See Figure 4.1.) Their efforts were enhanced when the State of Virginia passed legislation empowering the association with the duty to manage, maintain, and restore the property as a place of national importance for public education and enjoyment.

Comparable efforts can be matched by works of many other organized and individual endeavors nationwide. Restoration began in Sturbridge Village, Massachusetts (1859), in the historic district of El Pueblo de Los Angeles (1920), at Monticello, the home of President Thomas Jefferson (1923), in the historic core of Charleston, South Carolina (1930), in Colonial Williamsburg, Virginia (1930), and in New Orleans, Louisiana, in 1937 and again in 2005, following the devastating effects of Hurricane Katrina. These are but a few examples.

Key legislative actions by the U.S. Congress have fostered the growth and importance of historic preservation. They include the Antiquities Act of 1906, which concentrated national attention on the protection of specific building and archeological sites and was largely spurred by park and monument building efforts starting after the Civil War. The intent of this act was expanded in 1935 with the Works Progress Administration (WPA) of the National Recovery Act during the Great Depression.

Out of these programs grew the Historic American Building Survey, a work program calling for the measurement and photographic documentation of particular historic structures. In 1935 Congress passed the Historic Sites Act, which authorized the secretary of the interior to identify and acknowledge properties of value to national history and archeology. At this time the National Historic Landmarks Program and the Historic American Building Survey were permanently established within the U.S. Department of the Interior.

In 1949, Congress chartered the establishment of the National Trust for Historic Preservation, a quasi-public organization created to bridge the gap between private citizen efforts and government objectives to identify and preserve qualifying properties and sites of historic significance. In its creation, the trust served to officially recognize and unify over 100 years of grassroots citizen and government efforts to preserve significant sites and buildings.

In step with this commitment, Congress passed the Housing Act in 1961, requiring the secretary and Department of

FIGURE 4.1 Mount Vernon Homestead, a National Historic Landmark. (Photo courtesy of Hussein Shaban)

Housing and Urban Development (HUD) to identify, assess, and aid in the protection of historic properties within the guidelines for urban renewal activities.

Congress next passed the National Historic Preservation Act (NHPA) of 1966, amended in 2000, which became the principal federal law dealing with historic preservation. The NHPA established the National Register of Historic Places and encouraged state and local preservation programs, including the designation of a State Historic Preservation Officer (SHPO). It also established the Advisory Council on Historic Preservation, which is an independent federal agency that promotes the preservation, enhancement, and productive use of the nation's historic resources, and advises the president and Congress on national historic preservation policy. The two key statutory provisions of the NHPA are Section 106, which requires federal agencies to consider the effects of their undertakings on historic properties, and Section 110, which governs federal agency programs by providing for consideration of historic preservation in the management of properties under federal ownership or control. Section 110(f) requires additional protection for National Historic Landmarks.

Congress extended the protection and preservation of our nation's historic and archaeological resources to properties beyond federal lands with Section 4(f) of the U.S. Department of Transportation Act of 1966. Section 4(f) prohibits actions by the secretary of transportation that require use of a historic property that is listed on or eligible for inclusion on the National Register, unless a determination is made that there is no feasible and prudent alternative to the use of such land, and all possible planning has been undertaken to minimize harm to the 4(f) property.

President Lyndon Johnson's Housing Act of 1964, the "America Beautiful" campaign, and the Housing and Urban Development Act of 1968 propelled the private-sector preservation movement in negative reaction to federally funded urban renewal and reconstruction projects in numerous older city neighborhoods nationwide—Waterbury, Connecticut, being one example.

Another powerful event that strengthened the preservation movement and challenged development efforts is the 1978 U.S. Supreme Court's ruling to halt demolition of Grand Central Terminal in New York City (see Figure 4.2*a* and *b*). The Court ruled the train station to be of cultural, historical,

Figure 4.2a Grand Central Terminal, a National Historic Landmark. (Photo courtesy of Diego Santos)

FIGURE 4.2b Grand Central Terminal, a National Historic Landmark. (Photo courtesy of Diego Santos)

and architectural significance to citizens in New York City. The Court ruled that preservation of the building would not subject the land developer to an unjust economic burden.

The aforementioned legislative acts, in particular the Grand Central Ruling, established a precedent for future land development ventures. For the first time in U.S. history, all building types, including but no longer limited to those associated with the Founding Fathers and colonists, were now candidates for preservation as a function of their location and association with the heritage of a place. Second, preservation forces could effectively petition the courts to enjoin developers from demolishing or jeopardizing the historic integrity of a structure. The extent of such forces served not only to stop but also to redirect the design and development of an envisioned site program. Third, the decision challenged the intent of zoning. Whereas previously a landowner viewed zoning as the definition of existing or potential development for a particular land parcel, this ruling established that a land use zoning classification does not necessarily guarantee a right or expectation of development. Last but perhaps most important, this ruling also established a new concept for fair economic returns within the context of the private land development financial interest. It upheld that a profit is reasonable and expected by all private development efforts. However, the extent of that profit needs to be weighed against the costs that might otherwise be incurred with the loss of a historically significant structure or site. The ruling has been challenged many times and continuously upheld. When historic resources are in potential jeopardy, the privileges of private land ownership and development rights are placed under scrutiny.

Preservation and archeological exploration have come a long way since the 1978 Supreme Court ruling. As a movement and philosophy, they have grown far beyond the traditions of rebuilding and saving antiquities to the appreciation of built elements (buildings, land forms, and "things") common to everyday people that have merely survived time.

GETTING STARTED: KNOW YOUR PROJECT

An important factor that may be overlooked during initial planning for a land development project is the consideration of potential impacts on historic properties. Just as sites are researched and evaluated for their potential to contain environmentally sensitive areas, such as contamination and/or wetlands, so too must a site's potential to impact historic properties be considered early in the planning process.

The level of consideration is dependent on the undertaking and the regulatory climate. Here are some questions to ask at the beginning of the planning process:

- Does the proposed project require compliance with any local laws and regulations?
- Are there any local ordinances that deal with the treatment of historic properties?
- Are there any locally designated historic properties on the project site or in close proximity to the project site that could potentially be impacted?

After reviewing local laws, next ask whether the project is a state and/or federal action—that is, are any state and/or federal funds, permits, or approvals being used for the project? Any undertaking that receives federal funding, permitting, or licensing will require review under Section 106 of the National Historic Preservation Act of 1966. In addition, other federal laws such as the National Environmental Policy Act (NEPA) and Section 4(f) of the U.S. Department of Transportation Act of 1966 require the consideration of potential impacts on historic properties.

WHAT IS A HISTORIC PROPERTY?

The consideration of potential impacts on historic properties is an important factor in many land development projects. If a project requires review of potential impacts on historic properties, it is important to understand the criteria used to define a historic property. For compliance with local and state regulations, review of the regulation text is necessary to determine the definition. For federal undertakings, a historic property means a property listed in or eligible for inclusion on the National Register of Historic Places. In order to determine whether a property is eligible for inclusion on the National Register, the National Register Criteria for Evaluation are applied, as follows:

> The quality of significance in American history, architecture, archeology, engineering, and culture is present in districts, sites, buildings, structures, and objects that possess integrity of location, design, setting, materials, workmanship, feeling, association and:
>
> A. are associated with events that have made a significant contribution to the broad patterns of our history; or
>
> B. are associated with the lives of persons significant in our past; or
>
> C. embody the distinctive characteristics of a type, period, or method of construction, or that represent the work of a master, or that possess high artistic values, or that represent a significant and distinguishable entity whose components lack individual distinction; or
>
> D. have yielded, or may be likely to yield, information important in prehistory or history.

There are several criteria considerations. Ordinarily, cemeteries, birthplaces, or graves of historical figures; properties owned by religious institutions or used for religious purposes; structures that have been moved from their original locations; reconstructed historic buildings; properties primarily commemorative in nature; and properties that have achieved significance within the past 50 years would not be considered eligible for the National Register. However, such properties will qualify if they are integral parts of districts that do meet the criteria or if they fall within one of the following categories:

A. A religious property deriving primary significance from architectural or artistic distinction or historical importance

B. A building or structure removed from its original location but which is significant primarily for architectural value, or which is the surviving structure most importantly associated with a historic person or event

C. A birthplace or grave of a historical figure of outstanding importance if there is no other appropriate site or building directly associated with his or her productive life

D. A cemetery that derives its primary significance from graves of persons of transcendent importance, from age, from distinctive design features, or from association with historic events

E. A reconstructed building when accurately executed in a suitable environment and presented in a dignified manner as part of a restoration master plan, and when no other building or structure with the same association has survived

F. A property primarily commemorative in intent if design, age, tradition, or symbolic value has invested it with its own historic significance

G. A property achieving significance within the past 50 years if it is of exceptional importance

Historic Property Identification

Once the determination has been made as to whether a project will be subject to review under a local, state, or federal regulation, the next step is to identify whether any historic properties, architectural and/or archaeological in nature, are located within the project study area. Typically, this level of effort must be completed by a trained architectural historian or archaeologist who satisfies the professional qualification standards as set forth in 36 CFR Part 61.

Field inspection and background research are required in order to identify any potential resources. Often, an initial field inspection can indicate whether any buildings or structures exist on the project site or within the study area. General information about the project site's historic development, prior usage, and topographic features (such as its proximity to water) can help determine its potential to contain archaeological resources. In addition, visible land elements can be observed during the field inspection to help indicate whether a site might contain archaeologically relevant areas. Foundations, ruins, walls, wells, pits/dumps, and/or unusual vegetation formations are just a few examples of land elements that may indicate that a property warrants further investigation.

Many land development projects also require information from a surveyor. The information gained from the property survey could also be used to assist in the field inspection. Here is a list of important questions to ask and information to look for on record documents that can contribute to the site investigation:

1. Ask that title reports and deeds searched for land acquisition purposes be reproduced for file records and that appropriate notations be made regarding ownership and property improvements over time.

2. Request legal interpretation of references and notations on deed copies provided.

3. Secure copies of property plats, often referenced in deeds and required for financing.

4. If a new plat is required, ask the surveyor to research older, former plats, and to provide copies.

5. In the event deeds or plats reference improvements, relics, former events, subsurface conditions (wells, waste, burial), or information inferring historic or archaeological resources, ask for a definition.

6. Maintain records and communication. With good records and clear questions, a great deal can be resolved.

If properties are identified during the field inspection, further background research at local libraries as well as consultation with local historical societies and local historic preservation commissions can yield important information about the property's history and potential significance. Generally, when identifying historic properties, background research seeks to identify "known" and "potential" historic properties. Known properties are those that are officially recognized and include properties designated as National Historic Landmarks, properties listed in or determined eligible for listing in the National Register of Historic Places, properties listed in or determined eligible for listing in a State Register of Historic Places, and/or properties that are designated as local landmarks. Potential historic properties are those that are not officially recognized but, based on field inspections and background research, appear to satisfy criteria for official designation.

National Historic Landmarks are nationally significant historic properties that possess exceptional value or quality in illustrating or interpreting the heritage of the United States. All National Historic Landmarks are also listed in the National Register of Historic Places. In addition, the National Park Service maintains an online database—the National Register Information System (NRIS)—that contains information on places listed in or determined eligible for the National Register of Historic Places. The NRIS can be found at http://www.nr.nps.gov.

In order to identify known resources, it is necessary to consult with the State Historic Preservation Officer (SHPO). This often requires a visit to the SHPO's office to research their files and databases in order to determine whether any historic properties are located within the project study area. Information on both historic and archaeological resources can be obtained from the SHPO. Consultation with SHPO can also indicate whether there are other state-operated repositories for additional information on historic properties. Many SHPO offices also maintain online databases that could be consulted in order to identify historic properties.

In order to identify locally designated resources, consultation with the municipal historic preservation or planning department would be necessary to obtain information regarding local landmarks. Many municipalities have information about their historic preservation laws on their local websites and often list designated properties in their comprehensive plan.

Historic Architectural Resource Survey

When potential historic architectural resources are identified as part of a state and/or federal undertaking, a survey is often conducted in order to document the property. Generally, an architectural survey involves the completion of survey forms that record descriptive and historic information about the subject property. Many states have specific guidelines for the format of such a survey; consultation with the SHPO would be necessary to determine the level of documentation required. Upon completion of the architectural survey, the survey forms and possibly a summary report would be submitted to the SHPO for review. The SHPO would then comment on the property's eligibility for listing in the National Register. For local undertakings, it is recommended that the local law be consulted to determine the appropriate level of survey and documentation that would be required.

Archaeological Investigation

The identification and assessment of archaeological resources is typically conducted through a three-phase process. This approach is commonly used for federal and state actions and could also be used to satisfy the requirements of a local action, provided specific stipulations of the local law are satisfied. The first step involves a Phase I archaeological survey, which is typically conducted in two parts: Phase IA and Phase IB. Phase IA involves the identification of archaeological resources based on the results of previous archaeological investigations conducted in the vicinity, an understanding of the prehistoric and historic background of the project area, and the level of ground disturbance. Phase IB involves field excavations to determine the presence or absence of archaeological resources. Depending on the results of the Phase IB investigation, a Phase II investigation may be conducted in order to determine whether archaeological resources contain unique information regarding prehistory or history and warrant inclusion in the National Register of Historic Places. The third step—Phase III—consists of mitigation and involves either the avoidance of a resource or data recovery in the form of full-scale excavation and documentation.

LEGAL ISSUES PERTAINING TO PRESERVATION

There is abundant legal precedent affording protection to historic architectural and archeological resources at all levels: local, state, and federal. The law clearly sets forth limits regarding the disturbance of land and the improvements thereon. Land ownership and development carry the responsibility of being knowledgeable of such limits, especially with regard to the demolition of site improvements, the disturbance of cemetery plots, and the excavation of earth. While it is often difficult for local, state, and federal administrators to police every resource, penalties, fees, and criminal charges can result where deliberate action has resulted in the loss of property or artifacts that may be of historic or archaeological importance. It is prudent to secure legal advice at the earliest stage of land acquisition and program planning to gain a clear understanding of the rights and responsibilities affiliated with a development effort.

Williams Center, a mixed-use development project in Manassas, Virginia, was stopped by the reaction of one citizen who effectively organized a national movement to save a Civil War battlefield based on its archeological importance. Years of community outrage matched by extensive efforts on the part of the developer to study alternative designs and legal avenues for project realization saw the project end in a condemnation lawsuit in 1990. The court ruled that the property be purchased and preserved as a national park; this decision cost taxpayers millions of dollars for land acquisition and legal procedures. Perhaps early archeological investigation would have curtailed such an outcome? At least, in this case, early study would have afforded the developer more alternatives for land use or sale.

CONCLUSIONS

The role of historic property assessment within the land development process is continually growing and expanding. The traditional concerns of a property being historic in terms of age and national importance have branched into a wider arena, where contemporary issues of culture, heritage, community, environment, material use, and archaeology are of significant importance. Most land development endeavors recognize and plan for inclusion of these concerns. The emphasis of this section has been to increase the level of understanding of and appreciation for the role of historic preservation as a function of land change.

The cost to overlook resource assessment is substantial. Every legal case since Mount Vernon heightens this reality. The natural process of change spurred by economic supply or demand, profit, or the needs of people must be viewed in context with the real and perceived value history holds. The rate and degree of change serve to increase the importance of history, in part or in whole, to people. This section broadens both awareness of and appreciation for historic preservation as it plays a direct role in development.

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CHAPTER 5

ENGINEERING FEASIBILITY

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INTRODUCTION

Development projects often begin with the developer or landowner(s) approaching the land design team with a map or plat showing a piece of property, asking, "What can I do with it?" Others ask the question, "I would like to develop this for a specific use . . . can I?" The answers to those questions require more than a five-minute office consultation to check the property's zoning. The experienced consultant must recognize the unspoken parts of those questions that are perhaps more indicative of the level of investigation and commitment required: "Can I make a profit?" "Is the expense and effort worth the return?" "Can I complete the development in a reasonable amount of time?" "Will people buy what we have to offer in a predictable period of time?" "Can I make a valuable contribution to the community and my reputation?" Answering these questions requires extensive evaluation of all the components, participants, and dynamics of land development that impact the project and property.

Land development is highly regulated at all levels of government. The developer may spend considerable amounts of money to demonstrate that the development program and the design comply with those regulations. This must be done without any guarantees that construction will ever be authorized or profit realized. Furthermore, because the design, processing, and construction period can take several years, even a well-conceived project may find no buyers. Economic and demographic forces often change while the development program remains essentially the same.

In a competitive market where vacant land is in short supply, decisions must be made in a relatively brief period of time. Otherwise, the land may be lost to another buyer, usually a competitor. In periods of tight money supply and slow economic growth, the decision to purchase must be well reasoned. The developer must be assured that the investment will provide economic return. This is particularly true if rising land prices have not abated, despite weakness in the real estate market. The developer must base the commitment of resources to purchase land on a determination that the land will have future value and use.

Land development can be a risky business. To help offset that risk, an engineering feasibility study is often required fairly early in the development process in order to identify problems likely to be encountered during planning, design, government review, and construction, as well as to more resolutely determine potential uses for the land. It is this engineering feasibility study that aids developers in answering their basic questions and minimizing the risk incurred in purchasing land with the intent to develop or redevelop. Such questions include the following:

- What are the physical characteristics of the site? Are they conducive to the type of land development envisioned?
- What regulations apply?
- What are the costs involved to provide infrastructure to the envisioned development?
- What is the timing of the design and approval processes?

An engineering feasibility study is ideally commissioned and completed *before* the land is purchased. This study can take place either before negotiations with a landowner or during a purchase contract option period. If the study suggests that an unfavorable price has been asked for the property, the developer has an opportunity to reject the purchase or renegotiate the price. Meanwhile, the land is protected from purchase by other buyers. Failing to perform a thorough investigation can lead to costly mistakes and, in some cases, expensive lawsuits. At their first meeting, the consultant should advise the developer of the importance of performing an engineering feasibility study as part of the scope of services.

To perform such studies, one must understand the utility, value, and potential use of a tract of land. These are based on a number of underlying principles concerning physical and economic characteristics common to all land. Physical characteristics of land include its *immobility;* that is, it has a fixed location and cannot be moved to avoid or take advantage of other locational factors. In addition, from the government's standpoint, its fixed location makes it easy to regulate, tax, and attach. Land is *unique,* with no two properties being identical in size, shape, elevation, view, or access to natural and man-made resources. Notwithstanding certain natural forces that cause erosion, inundation, or landslide, land is *indestructible.* This reflects a stable investment. Economic characteristics include its *scarcity;* with no more land being created and unused land in increasingly short supply, land exists in a discrete quantity. The nature of *improvements* affects not only the value of the land but that of adjoining land as well. Land represents a *permanence of investment.* While certain improvements can be destroyed, the public infrastructure usually remains that investment which is characterized as long term and stable. Perhaps most important are the public's *area preferences* to location, which result in similar structures being valued differently in alternative locations (Galaty, Allaway and Kyle, 1988).

Physical constraints and opportunities of the site need to be identified and quantified to assist the developer in evaluation of the property. In addition to these inherent characteristics are those that affect its physical adaptability to certain uses. For example, consider two parcels of waterfront property—one flat, the other steep. The likelihood that the latter can be used for maritime purposes is limited. In addition, practical limitations on the mobility of humans, automobiles, machinery, and equipment affect convenience and ease of certain uses, especially when coupled with climatic differences. Roads, parking areas, and service drives must be designed to accommodate these limitations. For instance, if a road must be built on steeply sloped land, it may not be easily negotiated by an automobile. In climates where snow and ice are a factor, such a road may be rendered impassible for days or weeks at a time. The slope of sidewalks and trails must accommodate human capabilities. Long, steeply sloped walkways and stairways from streets and parking areas can be a hindrance to occupants as well as a market deterrent. In many instances, the law requires that access by people with disabilities must be considered. Graded slopes must safely accommodate maintenance equipment, such as mowers. While site grading during construction attempts to eliminate practical conflicts, existing topography and local ordinances sometimes make extensive regrading economically infeasible. The purpose of the engineering feasibility study is to establish a framework for making such decisions.

Finally, the value of land is affected by government regulations that control its development and use. These laws in many ways supersede and restrict the rights associated with land ownership while protecting the public's health, safety, and welfare. Development potential may be severely constrained by environmental factors. As a consequence, site development may not provide sufficient yield to return a profit. The cost of securing development approval or complying with local, state, and federal regulations may be so severe as to detract from a tract's value as a development site. Changes in development regulations may also affect parcel value.

Land developers who routinely operate in most communities already are very familiar with the land development process and expectations. The developer often is sensitive to the area's real estate market and can visualize project layout. Many are familiar with local attitudes and the political motivation of area leaders. Yet most developers engage consultants during the land acquisition (option) phase because of the need to assemble information prepared by unbiased professionals. Even if it was feasible to employ a large full-time staff of development specialists, their judgment might be considered prejudicial in negotiations with property owners. In addition, the consultant brings the benefit of the experience gained in working with many clients and projects. This cumulative knowledge about the process is valuable to even the sophisticated developer.

In some instances, the developer may be considering multiple sites. Each will have unique elements—location, topography, zoning, access, and/or infrastructure systems—that separate it from other sites. In this scenario, a site selection study should be performed to evaluate the sites based on similar metrics to determine which site is best suited for the development program.

In cases where rezoning is inevitable, there will be political and legal issues that will have to be addressed; an attorney familiar with zoning should be retained for these purposes (see Chapter 9 for additional information). The consultant may act as technical advisor to the attorney and developer; however, unless the consultant is extremely experienced with local regulations, he or she should refrain from offering legal advice. It is important to note, though, that the land design team will become involved with the *interpretation* and *application* of zoning ordinances and comprehensive plans. These interpretations are usually as important as the laws themselves, and become central to evaluation of the development for approval.

This chapter describes the important studies performed for the developer, leading up to the conceptual planning and detailed engineering required for the preparation of schematic and final design documents. It explains their purpose and utility to both the developer and government agencies, and includes discussion of the steps involved and resources needed to perform the analysis. Often the planner and/or engineer perform this analysis in coordination with other specialists or consultants as necessary. It is important for all members of the design team, whether they are involved in the production of the feasibility study or not, to understand the investigation process and the study results.

ENGINEERING FEASIBILITY STUDY

The engineering feasibility study[1] should evaluate the physical, environmental, regulatory, or other constraints that must be overcome or accommodated in constructing the intended use. The results of this study often affect the purchase price of the property, which is frequently based on presumed development potential. Uneducated assumptions about development potential frequently prove to be in error because of physical, locational, or external characteristics not properly considered.

The study is also important in providing legal protection to the prospective owner or developer. As discussed in the preceding chapters, the undetected presence of floodplains, wetlands, endangered species habitat, underground utilities, hazardous waste, contaminated soils or ground water, or other existing conditions could subject the owner to expensive cleanup operations or litigation under federal laws. The engineering feasibility study is often performed concurrently with the previously described environmental studies and usually references or even includes them as a component part or appendix.

The developer will use information from these preliminary studies to procure loans (verify due diligence) and begin the project go/no-go decision-making process. For this reason, the acquisition/feasibility study should be completed before the actual purchase of the land. The developer should insist on having a study period established as a contingency clause in the purchase contract. The purchase of the land may hinge on the information in the study as well as other contingencies. Time and money are the major concerns of the developer. The study is performed with the developer's funds. If the developer elects not to purchase the land, this is money that will not be recouped from the project. For this reason, it is to the developer's benefit to incur as little expense as possible at this early stage. Some purchases may be contingent on whether a rezoning or other application (such as special exception, variance, or subdivision) is approved. Others may hinge on whether a minimum number of buildable lots can be obtained. It should be emphasized that where there is a clear intent to rezone a parcel, land purchase contracts under consideration by the developer should include zoning contingency clauses such that if approval is not granted by the governing body, the developer is released from the obligations of the contract.

[1]An example of an engineering feasibility study report appears at the end of this chapter. Readers are referred to this report to get an idea of the types of graphics and information discussed throughout this chapter.

Because the seller wants to obtain the maximum price for the land and sell it in a reasonable amount of time, the study period specified in the contract may be on the order of only weeks or months. The buyer may be able to negotiate a longer time period within which to conduct the analysis. Normally, however, the buyer must be willing to compensate the seller for extraordinary periods of time. A higher purchase offering may be needed to extend the buyer's purchase option period. Because of the financial risk, the client needs accurate information in a short period of time. The decision to exercise a purchase option will be based on the information in the analysis/assessment study.

Most experienced developers will know the lowest value of a cost per unit that would render the project uneconomical. In practice, the developer may study several alternative uses based on the information compiled during the assessment period. This helps determine the uses that are economically feasible or whether the land development project can be profitable. Yield studies may also be performed in conjunction with each feasibility study. Depending on the skill of the design team, a seemingly poor site may be rendered profitable. In some heavily developed areas, there may be few options among alternative tracts of land, forcing land developers and design teams to more carefully consider less-desirable sites. Land often bypassed during earlier stages of a community's urbanization because it had characteristics that made it less suitable for development have, in recent times, increased in value because of their location and the presence of public infrastructure. Such sites may now be candidates for development if the higher development costs associated with resolving environmental and/or physical issues are compensated for by greater yield and prices now prevalent in their market.

Scope and Process of the Study

The study must be well organized and is usually supported by maps, photographs, and other graphics. It is often, but not always, presented in report form, although annotated base and topographic maps may suffice, depending on the client and the complexity of the project. Any biases or opinions by the author should be included only at the request of the client, and should be stated as such. The document will serve as evidence should any discrepancies arise or if lawsuits are filed as a result of claims for incorrect information.

The intent of the study is to identify development constraints or red flags along with options to minimize or alleviate those constraints. The study does not always specify preferred solutions. Those will be addressed later, if and when the developer moves forward with the purchase and development of the tract. Some site constraints, when recognized early in the process, can be accommodated by the plans and used advantageously in a variety of ways—most commonly as site amenities or for marketing and branding purposes. For example, in one project a wetland area was initially perceived as a major constraint. However, the constraint was turned into a unique design opportunity by incorporating the wetland area as part of a golf course where footbridges were used to navigate around the water hazard. Whereas the reviewing agencies were initially opposed to developments that impinged on the wetland area, incorporating it as an amenity helped to convince the agencies to approve the overall project.

The study approach varies with the developer's intentions, preconceptions, and circumstances related to the property. If the developer knows exactly what land use will be constructed and the zoning is compatible with that use, the feasibility study will analyze the site in accordance with that use and zoning. If the use is uncertain, the study will identify land use options based on the potential of the land. The potential of the land takes into consideration the ultimate density (derived from existing and master planned zoning designation) in the context of the existing and planned infrastructure and public facilities. The developer may wish to consider several options; the consultant may need to perform several feasibility studies if there is a significant variation in land use permitted by the possible zoning.

Frequently, the client will require a cost estimate for the construction of certain items in the study, such as utilities, road, and other infrastructure improvements. Additionally, unusual or extraordinary costs will be identified and estimated. This helps in assessing the economic feasibility of the site. The study is not intended to offer solutions to site problems; it is merely to identify opportunities and constraints and as such serves as an invaluable resource in preparing for subsequent phases of design should the developer decide to purchase the land and pursue the program.

Required Information

The engineering feasibility study requires a comprehensive collection of all information that could affect the site and its development. For purposes of this section, the research and analysis associated with an engineering feasibility study are categorized into three types of information:

1. Legal condition of the site such as easements, land rights, and other property encumbrances

2. Physical condition of the site such as topography, soils, utilities, drainage, and external influences created by neighboring properties and uses

3. Regulatory concerns of the site such as applicable master plans, zoning and ordinance requirements, possible citizen opposition, and governmental review considerations

Such items have a significant impact on how the land is developed and how successful the project will be.

Legal Condition. Title investigation must be performed by an attorney or title insurance company for the developer to ensure that the landowner holds a fee estate in the subject property. The following title and other property information should be reviewed to determine the legal constraints and opportunities of the site:

- Land ownership records, including property description (using metes and bounds or the government survey method). Do these records match the scope of the project? Will land be excluded from the project, and do subdivision regulations allow such exclusion? Is the property contiguous, or are there portions of the property separated by rights-of-way (ROW) or other properties?

- Chain of title traced back to the creation of the tract boundaries or the adoption of local subdivision regulations, whichever is earlier. A title company usually performs a title search to ensure, and ultimately insure, that the chain of title has not been broken. The purpose of the land design team's analysis is to determine the applicability of local development regulations. Has the subject parcel been legally subdivided from its parent tract (that is, with government approval if such approval was required at the time the parent tract was split)?

- Deed conditions, restrictions or covenants that could affect future use and enjoyment of the property. Is the proposed use prohibited by deed? What private deed restrictions are imposed on the final land use, such as lot size, setback from property boundaries, architectural style, or building material? Is any portion of the tract, such as a lot around an existing dwelling, to be reserved for the existing owner? Is the property or a portion thereof restricted from development through local, state, or federal programs such as Farmland Preservation, Green Acres, Open Space Preservation, or other transferable development rights (TDR) program? Although federal programs do exist, many of the current preservation programs are managed by local or state agencies. Typically, the preserving agency places a deed restriction on the property limiting its use to specific activities such as agricultural (as in the case of Farmland Preservation) or active/passive recreation (Green Acres or Open Space Preservation). Depending on the mandates of the preservation program, the deed restriction may run for a limited duration or in perpetuity and is binding to future owners of the property. TDRs are discussed further in Chapter 7.

- Prior recorded plats, including government takings, boundary adjustments, and subdivision plats. If there is an existing subdivision plat of record, what is its status? Can it be used advantageously? Can the lots be developed and sold? What are the developer's responsibilities concerning platted public improvements, such as streets and storm drainage? What other requirements would apply? Identify local procedures for street, ROW, or easement vacation and abandonment.

- Records of easements appurtenant (usually providing access to or through the property or adjoining properties) and in gross (usually energy or communications transmission lines), showing purpose and holder of the easement. What rights are accorded the holder and what limitations are placed on the developer's use of the easement? Can easements be abandoned or relocated? Are there potential instances of adverse possession or prescriptive easements on the property? Refer to Chapter 6 for more detailed definitions of the aforementioned legal terms.

Physical Condition. Research and review of the site's physical attributes and constraints includes the site location, access, topography, drainage, vegetation, soils, and utilities. The following information must be assembled and reviewed to determine the physical constraints and opportunities of the site.

Location:

■ Configuration and site area from tax maps and tax records. Is this mapping, site area, and ownership information consistent with the title information?

■ Existing structures, paved or developed areas, fences, and walls. Are all improvements contained within the site boundaries?

■ Adjacent properties, including information on ownership, zoning, land uses, and their proximity to property boundaries.

■ Encroachments from structures on adjoining properties, including existing access ways that may lead to claims of adverse possession or prescriptive easements.

Access:

■ Presence of landlocked parcels and other properties adjoining the subject property. These may require extensions of roads and utilities as part of a development plan (see Figure 5.1).

■ Public road frontage and property access information. Who is responsible for maintenance and repairs of frontage and access roads? Is the property's frontage on a public road sufficient for gaining proper access to the future development? If there is no frontage, are access rights-of-way to public roads of sufficiently short length and adequate width to accommodate local street requirements? These standards include width, grade, drainage, and maximum cul-de-sac length. Is there sufficient room for construction equipment to maneuver? If not, can additional land or access be acquired? Will there be adequate sight distance at proposed entrances, as well as

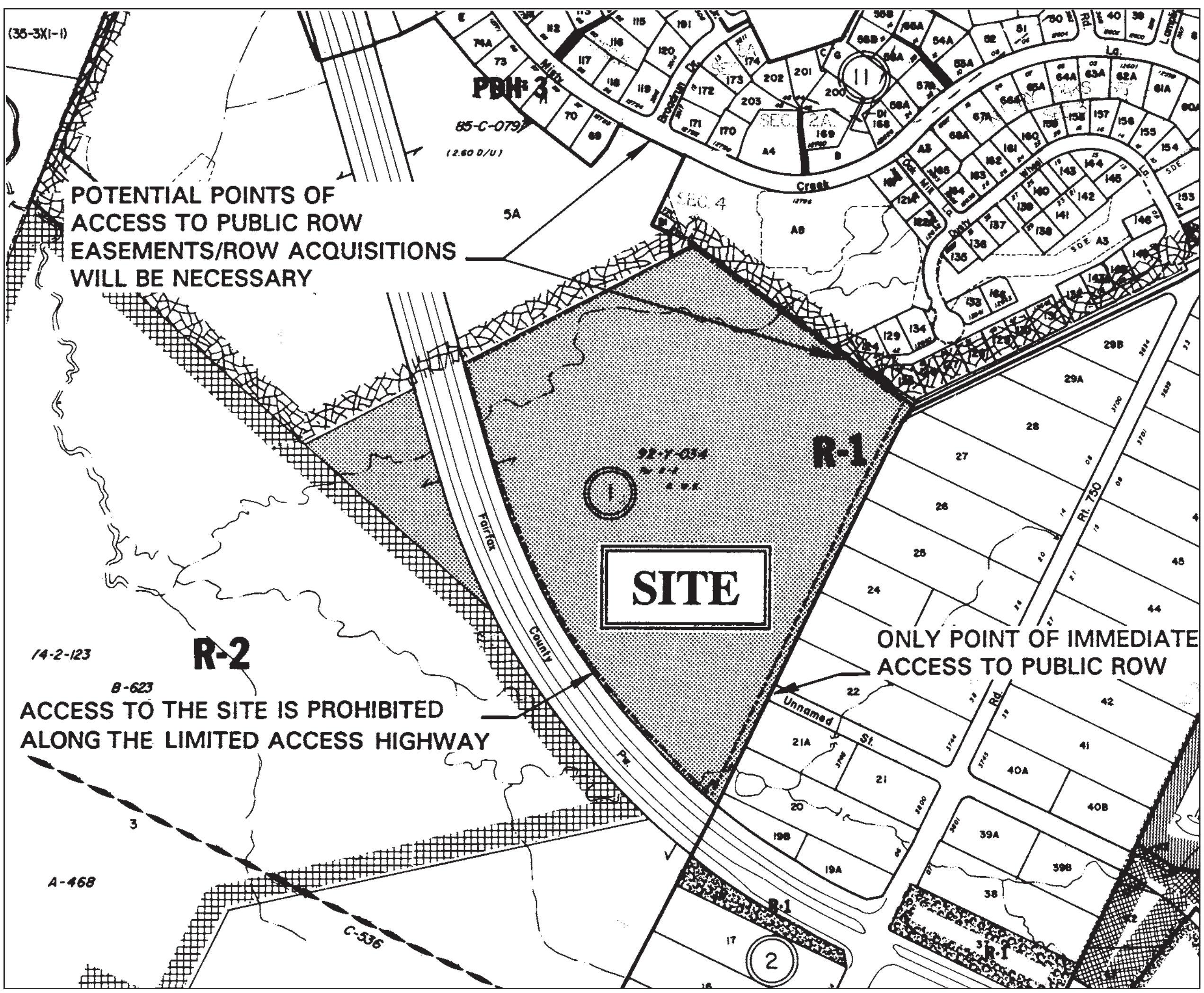

FIGURE 5.1 Landlocked parcel, due to property lines, that could necessitate extension of public infrastructure by the developer.

vertical and horizontal road curves? Is there sufficient frontage to provide proper spacing between road entrances?

- Existing roads, both adjacent and across from subject property, and road conditions. Include right-of-way width, pavement width, sight distance at hills and curves, sidewalks, curb and gutter, and drainage swale information. Indicate conditions that might hamper flexibility in site design. For example, requirements for minimum spacing between intersections on the abutting roadway may limit potential entry points to the development. Large trees at the edge of pavement may prevent widening or draw public opposition. Will any existing streets or rights-of-way require abandonment or vacation?

- Will existing and proposed highways in the vicinity of the site generate highway noise that should be mitigated?

Topography:

- In performing a topographic analysis, identify streams, swales, ridges, and similar landforms and features. Identify steep slopes where grading may be expensive or prohibited (greater than 15 percent and 25 percent) and excessively flat areas (less than 2 percent) where storm and sanitary sewer drainage may be difficult or expensive to achieve. Show an incremental breakdown of intermediate slopes to assist in plan layout. (See the report at the end of this chapter for a topographic analysis.)

Storm Drainage:

- Drainage basin and watershed within which the property is located; unique restrictions or conditions applicable to development.

- Description of on-site drainage patterns.

- Location or plans for regional stormwater management facilities; timing of public improvements.

- Existing floodplains from local jurisdiction, U.S. Geological Survey (USGS), or Federal Emergency Management Agency (FEMA) reports.

- Potential for floodplain when stream is present. Small streams and swales not flowing continuously throughout the year may still need to be analyzed for their flood capacity and status as jurisdictional waters.

- Probable locations and sizes of culvert and outfall improvements due to increased runoff from development.

- Downstream problems with drainage; known complaints.

- Requirements for non-point-source pollution control and best management practices (BMPs) during construction and subsequent to final development, including performance requirements for stormwater quantity and quality and ground water recharge.

- Stormwater management facility design constraints, including review of apparent seasonal high ground water elevations. Will the existing ground water table dictate the use of retention basins (wet ponds) with permanent pools of water or significant amounts of imported fill to maintain dry detention basins?

- Evaluation of adequate outfall, including presence and/or provision of necessary easements for access and maintenance, current physical condition and ownership of existing structures, or potential site improvements necessary for new outfall.

- Location, size, depth, and condition of existing pipes.

- Overland relief constraints from downstream properties and potential overland relief constraints of the subject site to upstream properties.

- Location of wetlands and other sensitive environmental areas (from National Wetlands Inventory maps) or other available mapping.

Vegetation:

- The location of large (species) trees and areas of tree cover, including a review of the quality and type of existing trees, should be determined.

Soils:

- Soils information, including types and characteristics, bearing strength, stability, shrink/swell potential, perched ground water table, estimated seasonal high water table, presence of naturally occurring asbestos, radon potential or existence of residual pesticides from historical agricultural uses, and suitability with regard to building foundations, stormwater management facilities, culverts, utility trenching, and erodibility. Consider soil percolation characteristics; do soils indicate the need for extensive earth movement and placement of engineered foundations on compacted fills? Where soils of questionable suitability are identified, the consultant should recommend that further investigation and testing be performed by a geologist or other expert.

Sanitary Sewer:

- Agency with ownership and approval authority.

- Sewershed in which the property lies; available capacity, projected demand, and local restrictions concerning sewer allocation.

- Location, size, depth of, and distance to existing lines.

- The age and condition of existing lines in order to evaluate whether current materials are compatible at connection points and whether the type of pipe will be structurally adequate for proposed uses over the line.

■ If not on-site or adjacent, the distance to appropriate connections, the means of access, and the need for easements.

■ Responsibility for extension and improvements and current timing of public improvements; potential for reimbursement from public or private funds, such as other developers.

■ Gravity versus pumped versus on-site package treatment plant.

■ Interference of system construction with other utilities/features.

■ Pro rata shares or assessment fees.

■ The age and condition of existing lines in order to evaluate whether current materials are compatible at connection points and whether the type of pipe will be structurally adequate for proposed uses over the line.

■ On-site disposal issues, including treatment method, soil suitability, drainfield and lot size restrictions, impact on project density/lot size, comprehensive plan and ordinance considerations, and depth to water table. Spot percolation tests may be required.

Water Distribution:

■ Agency with ownership and approval authority.

■ Size, location, and depth of, and distance to existing water mains, means of access, and need for easements. Are off-site easements required to extend service?

■ Water quality, quantity, pressure, and necessary corrective measures.

■ Responsibility for extensions and improvements, and associated fees; timing of public improvements.

■ Requirements for fire hydrants; water supply and distribution requirements for fire flow.

■ The age and condition of existing lines in order to evaluate whether current materials are compatible at connection points and whether the type of pipe will be structurally adequate for proposed uses over the line.

■ On-site well information, including depth to water table, ground water quantity, water quality, plan, impact on project density, proximity to dwellings and septic systems, and other ordinance requirements. Test wells may be required.

Information Concerning Other Public or Private Utilities and Services:

■ Service options for energy and communication utilities, such as electric, gas (natural or liquid propane), cable, telephone, and fiberoptic. Are there competing companies serving the same area? If so, are rate structures and builder incentives comparable?

■ Current and projected levels of service. Are improvements budgeted and is the timing compatible with the project? Can the timing be advanced?

■ Responsibility for design, upgrade, and connection.

■ Consideration for required easements. Who will obtain them?

■ When must connection fees be paid?

■ Electric, telephone, and cable undergrounding requirements; on-site, adjacent, and off-site responsibilities and contributions.

■ Information regarding the provision of trash removal and recycling (curbside pickup), street cleaning, snowplowing, and similar services. Are services public or private, and are there alternative providers? If trash removal is public, is it available to condominiums and commercial operations? What is the availability of private contractors for these services?

■ Location, proximity, and planned improvements of elementary and secondary schools and means of access (pedestrian, school bus, and public transit). Do sidewalks or trails exist between the site and schools? Will interior sidewalks be required in the development? Are there school impact fees?

■ Requirements and responsibility for installation and maintenance of streetlights.

Other Aspects of the Site:

■ Availability, proximity, and planned improvements of emergency services, such as police, fire, and rescue.

■ Aircraft flight patterns and noise contours.

■ Unusual on-site and adjacent features, such as cemeteries, railroads, and historic properties.

■ Natural hazard (i.e., earthquake or flooding) potential, prevailing weather patterns, and solar exposure that could affect the project design.

■ Research into previous uses, needed to determine possible underground structures or contaminating conditions.

Regulatory Concerns. Regulatory information must be included in an engineering feasibility analysis in order to identify the appropriate processes to allow the proposed development. These processes will influence the timing, cost, and extent of community and public involvement in the development process. The following aspects of an engineering feasibility study will aid the developer in the assessment of the regulatory aspects of a proposed project.

Planning, Zoning, and Related Development Information:

■ Relevant comprehensive plan, zoning maps, and texts. These include growth management ordinances, such as adequate public facilities ordinances, impact fees, and other construction limitations such as annual building permit caps. Include information on miscellaneous fees, such as filing and processing, recreation, and drainage. When must fees be paid and improvements installed?

- Current property zoning and proposed zoning, including uses permitted by right and those requiring special exception. Describe the purpose of the zoning district. Do zoning boundaries divide the subject property? What is the relationship of zoning district boundaries to the subject property?

- Requirements for zoning overlay or special districts. Examples of such districts include highway corridor, historic, transit area, central business district, transfer of development rights, resource protection, conservation, or other management areas allowing credits for increases in the permitted base density of development.

- Comprehensive plan recommendations peculiar to the site, for example, density or allowable land use. Does the current comprehensive plan show any roadway improvements that will impact the site?

- Pertinent requirements of the zoning ordinance. These include maximum density or floor area ratio, minimum or average lot size, setbacks (from project boundaries, property lines, lot lines, rights-of-way, railroads, highways, waterfront, etc.), building height and bulk requirements, maximum lot coverage and open space requirements, off-street parking and loading, screening buffering, and landscaping requirements. Is right-of-way of future roadways used for density credit?

- Proposed or pending changes in comprehensive plans or development regulations likely to be adopted within the project's life span. What significant impacts will these changes have on the property's use or yield? Will the change increase the time it takes to secure construction authorization or expose the project to additional public hearings or government agency review?

- Grandfathered or vested rights that may be jeopardized by the proposed development. Will the project be exposed to requirements far beyond those needed for the additional construction or expanded use?

- Development history of the property, including records of previous submissions for rezoning, special exception, subdivision, or building permits.

- The likelihood of citizen opposition and delays associated with the development process. The experience of the land design team is particularly valuable here. Familiarity with local issues and past encounters with civic groups can help the development team prepare for future conflicts.

- Subdivision and other ordinance regulations peculiar to the site, such as lighting or signing ordinances, and tree or historic preservation or planting ordinances. Can private streets be utilized?

- Will there be any assessment by any local or state agency for road construction? Are there requirements for adjoining property owners to contribute to the cost of constructing streets to service their properties?

- Requirements for green building design. In general terms, *green building* refers to site development and building design that promotes energy and resource conservation and produces a healthy and productive environment (internal and external to the building) for people to work and live in. Many federal, state, and local jurisdictions have adopted a certain (accredited) third-party green building certification as a mandated standard or require that a project design demonstrate the ability to attain a specific level of certification. Several third-party review agencies currently exist, each with differing evaluation criteria. Determination as to what guidelines, if any, will apply to the proposed development based on the regulatory climate and owner/developer preference should be made in the early stages of engineering feasibility. Further discussion of typical elements of green building design and items to consider during the engineering feasibility are presented at the conclusion of this chapter.

Based on the preceding information, a checklist such as that shown in Figure 5.2 can be created to facilitate the feasibility study.

Sources of Information

The land design team must become familiar with information resources and the local sources of that information. These simplify the investigation of property conditions and local regulations, and they eliminate much of the need for original research and testing. Throughout the study phase, sources must be documented with particular care, whether the sources available are public documents or conversations with public officials. This is especially important in preparing the final report document, where the consultant's opinion must be separated from others' opinions or established facts.

Of particular value are existing public records. These include published tax maps of the community, which depict property boundaries, land area, and landowners, along with references to recorded subdivision plats and deeds. An office of land records, court clerk, or similar agency maintains copies of deeds, subdivision plats, and similar records relating to property ownership.

The local planning, public works, building, or transportation department often maintains aerial photos of the community, taken at various intervals. These provide both historic reference as well as indications of recent or current use. These photographs often are printed in conjunction with tax maps of the community.

Some communities provide topographic maps of the community based on aerial photography. Otherwise, these are available from private sources or can be commissioned for each project. In addition, the USGS quadrangle maps are useful for identifying site topography, natural and man-made features, perennial and intermittent streams, and other items of interest to the consultant. In many communities, the local Soil Conservation District or state natural resources agency publishes soil maps and related information.

Recent building and development plans, permits, and application materials often are kept on file in various agencies, either in their original files with all supporting docu-

PROJECT NAME: ______________________ DATE: ______________

TAX MAP REF: ______________________ DATE DUE: ______________

I. Administrative Checklist

A. Check files to determine existence of current or previous studies for subject or nearby sites.

B. Obtain pertinent plans for existing or proposed developments in vicinity of site. This also applies to proposed public improvement projects which may affect subject site's development.

C. Site Visit

1. Vegetation, tree coverage, and any unusual conditions found on site.
2. Onsite steams and adequacy of outfall channels both onsite and offsite.
3. Note culverts (type and size) along outfall.
4. Note existing utilities onsite and adjacent to site.
5. General topography and soil conditions, including rock outcrops.
6. Check site distance of road frontage.
7. Note existing structures onsite and proximate to the site.
8. Note size and condition of roadways.
9. Note indicators of potential wetland areas.
10. Note indicators of environmental contamination.
11. Note current construction activity on or near the site.

II. Written Feasibility Study Checklist

A. Legal

1. Land ownership records (tax records).
2. Title information and easements.
3. Deed conditions and covenants.
4. Subdivision history.

B. Physical

1. Location, type, and condition of existing structures, paved areas, fences, and walls.
2. Adjacent property ownership, land use, encroachments, access and other potential impacts.
3. Public road frontage, sight distance, access constraints, noise impacts.

FIGURE 5.2 Checklist for acquisition/feasibility study.

4. Site topography, steep slopes, flat areas.
5. Drainage basin and watershed impacts. Onsite drainage patterns, existing water bodies, floodplains, outfall conditions, downstream drainage problems, stormwater management requirements, overland relief constraints, potential wetland areas.
6. Location, type, and condition of vegetation.
7. Soil information from existing records and other pertinent studies.
8. Sanitary sewer information including sewershed, location and size of existing lines, condition of existing facilities, capacity of existing facilities, extent of improvements necessary to connect to existing facilities, potential conflicts with other utilities, pro rata assessments, onsite disposal options.
9. Water information including size & location of existing lines, pressure in existing lines, fire flow requirements, condition of existing lines, extent of improvements necessary to connect to existing facilities, potential conflicts with other utilities, pro rata assessments, onsite water supply options.
10. Natural gas, electric, telephone, fiberoptic review including franchise, availability, and proximity to site.
11. Other impacts such as trash removal, location of schools, street light requirements, emergency service proximity, aircraft noise impacts, onsite cemeteries, historic aspects, endangered species, prevailing winds and solar exposure, potential environmental contamination.

Regulatory

1. Zoning requirements.
2. Master plan/comprehensive plan recommendations.
3. Proposed or pending changes to the ordinances.
4. Grandfathering or vesting rights.
5. Development history of the site.
6. Local development issues and concerns.
7. Subdivision regulations.
8. Development process and timing.

FIGURE 5.2 (*Continued*)

ments or on microfilm or another medium. Most are available for public inspection. These provide records of previous studies that might apply to the subject property. Along with public records of construction plans and as-built documents for public facilities, these records are useful for information relating to underground utilities. These files often provide useful information concerning the experiences of previous developers. The development consultant's own in-house records of its previous and ongoing projects near the development may contain recent studies or more current information than that available from other sources.

Copies of local plans, regulations, and ordinances are available from these agencies. The community's comprehensive plan may list local, state, and federal sources for information upon which the plan is based. The transportation agency may have recent studies of existing traffic counts, capacities, and level of service for the road network near the project.

A local historic preservation agency or society may have compiled a register of historic properties or sites, including archeological information. The local economic development authority or chamber of commerce provides useful market area information. The local utility companies will provide distribution maps of the service areas.

Many federal agencies provide maps of various utilities to the consultant team. In addition to USGS and FEMA, these include U.S. Fish and Wildlife Service, Army Corps of Engineers, Environmental Protection Agency, and Natural Resources Conservation Service.

With the increased reliance on the Internet and computer technology in today's society, most of the aforementioned local, state, and federal agencies provide data electronically, either for free or for a small fee. A good portion of the available information can be accessed directly from the Internet via the agency's website and downloaded for use in reports and design documents. If the specific agency does not have an Internet site, other, independent sites may provide a compilation of data such as ordinances, tax maps, zoning maps, aerial maps, or other information contained in Geographic Information Systems (GIS). However, care should be exercised when utilizing data obtained via the Internet, as the available information may not be current due to delays in the Internet site obtaining and posting updates or modifications to existing regulations. The most common problem occurs with online review of local ordinances and zoning maps, where an independent data provider has not obtained and posted updates from the municipality for an extended period of time. Care should be taken to review the frequency at which any online source updates its information, and a simple call to the local agency for data verification is recommended. The desktop review is a critical component of the feasibility study: information obtained in this manner can help streamline the site visit and records review, allowing consultants to focus on acquiring specific missing data and confirming collected data.

Once all information is retrieved and compiled, the land design team prepares base maps of the subject property at a level of detail and accuracy commensurate with the time and budget. The most common map scale to use is 1 inch = 100 feet or 200 feet, although for smaller properties, 1 inch = 50 feet may be more suitable. The selected scale should be suitable to show sufficient detail. For many projects the 1 inch = 100 feet to 1 inch = 200 feet scale range is adequate to show the detail and yet limit the number of drawing sheets to only one or two. The base map is prepared on topographic maps or contour maps. Contour intervals of 5 to 10 feet are readily available and acceptable, except perhaps in very flat areas, where a closer interval may be desirable. The base map should show property boundaries with dimensions and intersecting property lines from adjoining parcels. Adjoining roadways and scaled locations of all other physical features identified in the information-gathering stage are also typically shown. These will be verified and information expanded in the next step of the assessment study—the site inspection.

Site Inspection

One of the most important elements of the feasibility study is the site inspection. Much of the information garnered during the desktop review is outdated, reflecting only property conditions at a specific date in the past. Physical conditions change constantly through the action of both people and nature, and maps may not accurately represent the actual field conditions. In addition, contours and other information normally shown on aerial topographic maps may be unclear. The ground may have been obscured by foliage or snow cover, depending on the season of the year, time of day, or other conditions at the time the area was flown. A site shown as wooded may, in fact, have subsequently been cleared and graded. Illegal dumping or similar activity may have taken place. Adjacent properties may have undergone development since the maps were last produced. Certain features, such as wetlands and small streams, may not readily be evident and often require field analysis to verify their location.

For these reasons, it is imperative that a field inspection be performed as part of the engineering feasibility study. The visit is necessary both to verify and to build upon information collected elsewhere. The person visiting the site is looking for obvious contradictions with recorded information, as well as evidence that implies conditions not previously known. Of particular importance are conditions that may render the land unusable or impose extreme costs in the development.

Prior to visiting the site, the field personnel assemble and prepare information in advance. In addition to the base map, a clipboard, writing paper, tape measures, scales, waterproof pens and markers, a digital camera or even a video camera, and plastic bags for collecting specimens should be among the equipment brought to the site.

It is imperative that the field visit team make arrangements with the developer, the owner, and any residents of the site prior to the site visit. Agents of the developer may not necessarily have right of entry if it is not spelled out in the purchase contract. Occupants might not welcome unexpected visits, as they may not even be aware that the property is being sold. Ask that dogs and other animals on the site be penned, if possible, as a protective measure. The field team should also verify with the developer and owner that no known environmental hazards exist on-site in order to adequately prepare and protect field personnel.

The consultant should be appropriately dressed for the visit, anticipating the weather, brambles and dense brush, mud, standing water, poison ivy, insects, snakes and other wildlife, and any predetermined environmental conditions. One of the purposes of the field inspection is to determine the site's response to rain and runoff. Therefore, it is advisable to schedule at least one visit to the site during or soon after storms or spring thaws. The field team can observe ponding, running water, and other surface conditions that otherwise may not be visible.

Upon arriving, the consultant should drive the boundaries of the site, noting landmarks such as fences, hills, swales, and curves in the roadway that have previously been recorded on the base map. These will serve as points of reference while walking the site and make it easier to record information about the visit. A systematic walking tour of the site should be planned, taking care to include critical natural and man-made features that were previously noted in the office review of site information.

On the base map, note and verify those areas that are important to the development of the site, either as problems or as opportunities. Outline the apparent boundaries between different topographical and geological conditions, such as between improved and unimproved areas, stable and unstable slope areas, wetlands and dry ground, and wooded areas and open fields. Visualize property boundaries, particularly in locations where topography or other circumstances appear to create difficulties during development. Depending on the relationship between the site boundaries and the topography, construction in these areas may necessitate the acquisition of easements for drainage or equipment access across adjoining properties. Retaining walls may be necessary at property boundaries if significant grade changes are required.

Areas of interest that should be recorded on base maps during the field reconnaissance are described as follows:

- Streams, swales, washes, and evidence of confined running water and intermittent streams, such as unusual patterns of fallen leaves, vegetation and stones, soil erosion, uprooted or undercut trees, and areas cleared of leaves.
- Ridges and obvious drainage divides with nearby running or ponding water at lower elevations, indicating high water table, springs, and springheads.
- Floodplains, often evidenced by high water marks on shrubs, tree trunks, and low-hanging branches.
- Ponds, lakes, and other impoundments, trying to identify the limit of impoundment.
- Evidence of pollution or sedimentation in running and standing water, from on-site or off-site uses.
- Condition of stream valleys, banks, and shorelines.
- Marshes, swamps, wetlands, bogs, and wet and soggy areas, noting types of vegetation, areas of matted leaves, or unusual soil coloration that may suggest frequent or periodic inundation.
- Areas and types of vegetation, boundaries of wooded areas, and stands of trees that might serve as buffers against adjoining properties, protected species, large trees, and other specimen trees or mature ornamental landscape materials that may be preserved, either in place or transplanted for subsequent reuse in the development.
- Presence of fish and wildlife and evidence of animal habitats, such as beaver dams and eagle aeries that must be considered and protected, or that may even preclude development of the property.
- Cliffs and other unusual landforms indigenous to certain areas of the country, such as coastal and Great Lakes dunes and sinkholes.
- Areas of steep slopes, noting vegetative cover.
- Evidence and sources of erosion and slope instability, such as leaning trees, poles, fences, broken pavement at the top of a slope, softness at the toe of a slope, sharp vertical drops suggesting landslides, and other signs of previous slope movement; exposed soil colors.
- Locations where, based on visual inspection and soil map data, additional subsurface explorations (e.g., auger boring, test pits) will be necessary.
- Evidence of strong prevailing winds, such as distorted plant and tree growth.
- Existing pilings and retaining walls.
- On waterfront property, piers, moorings, and other marine uses, and access points to the edge of the water. Observe conditions and uses of adjoining and opposing shorelines, maritime activity, and information concerning water quality, depth, and bottom configuration.
- Rock outcroppings, which may create problems in site excavation for roads, utility trenching, well and septic system suitability, and foundations. Consider their possible use as aesthetic features and points of interest to enhance the development's market appeal. It may be possible to stockpile stone and rock for subsequent use in erosion and sediment control or for landscape material.
- Condition, size, and location of culverts, outfall channels, and any existing drainage pipes and swales.
- Location, use, and structural condition of buildings, paved areas, abandoned wells, and other man-made features on the site, and whether or not they are to be preserved; evidence of flood damage, earth settlement, and movement in walls and foundations.
- Evidence of cemeteries, grave sites, burial grounds, archaeological and historic sites, battlefields, old foundations, and other unusual or unexpected existing or prior land uses on-site that could limit development potential, incite community opposition, or delay project approval.
- Evidence of trespass and community use of the property, such as footpaths, dirt bike trails, picnic areas, and sports fields, which may be an indication of potential community opposition to the development.
- Interesting views within and from the site; areas that might be cleared to enhance views and views from adjoining properties onto and over the site.
- Character, condition, and use of adjacent property, and proximity of neighbors and site improvements. Record evidence of access easements and encroachment of fences and structures.
- Current construction activities on or near the site.
- Evidence of noise, smoke, dust, odors, light intrusion, or other activities from sources within the site or nearby uses, such as from industry, highways, railroad crossings, racetracks, hospitals, fire and rescue stations, schools, commercial areas, airports, landfills, sewer lines, or sewage treatment plants. These could affect the site's value or market appeal. Prevailing winds should be considered, evaluating their impact. Noise walls, landscape barriers, or special construction techniques and materials may be employed to mitigate a potential nui-

sance. Evidence of significant trash, debris, chemical or oil dumping, burial and storage. Evidence of unusual odors that may suggest natural decay, sensitive environmental features, or ground contamination.

- Sight distances at curves and hills adjacent to the property and probable entrances.
- Traffic congestion on adjoining roads and nearby intersections.
- Condition of surrounding roads and pavement, including paving and shoulder stability and widths, roadside swales, curbs and gutters, and location of nearby and opposing driveways.
- Locations of overhead utility and power transmission lines.
- Manholes, standpipes, vent pipes, signs, and other evidence of underground tanks, sewers, and transmission pipes. An isolated area with poor vegetation, in contrast to its surroundings, may be indicative of subsurface materials.
- Possible locations of individual and clusters of buildings, internal roadways, and open-space areas, trying to visualize development of the site. Record existing and potential means of access to areas separated by deep swales and ravines.

Depending on the size and scope of the project, several individuals may be required to walk the site. In addition, it may be necessary to revisit the site with other professionals whose expertise is indicated by the findings or local requirements. Further analysis may be required where preliminary investigations show the presence of unusual soils or wetland areas. Additional site visits will be needed if the project moves beyond the feasibility study. Therefore, as thorough an inventory as possible at this phase will simplify later work. However, this must be balanced with efforts to control costs at this phase. These costs must be controlled because of the possibility of project abandonment.

During the site visit, extensive photographs should be taken. The location and direction of each photo should be noted on the base map for reference in the office. These should include photographs of important views and significant features. A series of panoramic shots taken from the property boundaries is useful for setting points of reference. Including people or other items of known size helps establish height, depth, and width of features being photographed. As in all photography, lighting and shadows are important for adding dimension. Photographs serve as valuable reminders when the site inspection is studied back in the office. In addition, photographs assist other members of the development team who were not present in the field. Videotaping the site visit provides a useful reference, allowing for more interactive commentary about site features. It also provides a clear record of site conditions prior to development. This is useful for comparison to conditions during and after construction if legal or procedural conflicts arise. Figure 5.3 shows how site photographs can be referenced to the property.

Site Analysis Mapping and Report

Data from the site visit must be compared to other recorded data. Any inconsistencies should be resolved to verify true field conditions. Of particular importance are discrepancies in property boundaries and topography. The consultant should transfer information to a clean base map, which will be used to report the results of the study to the developer. In addition, the map becomes an important tool in performing yield studies and beginning the design process should the project advance to that phase.

The relationship to the site of existing roadways, utilities, and other facilities should be shown. Site constraints should be noted and labeled, using shading, heavy outline, and other techniques to identify areas of the site that are totally unusable or usable with significant corrections. These include floodplain areas, unstable or erodible soils, or soils of poor bearing capacity, steep slopes, wetlands, and other environmentally sensitive areas that local state and federal regulations accord special treatment. Area measurements of these encumbrances are recorded on both the map and in tabular form in the report.

The map should indicate those facilities and improvements that will be necessary, because of function, industry practice, or government regulation, to develop the site. These include probable vehicular access points, along with an assessment of improvements to public roads that will be needed to facilitate safe, convenient access. A consultant experienced with community policies will know whether site development will require turning lanes, acceleration or deceleration lanes, medians, or traffic control devices. Even if not required, the consultant should be familiar with expectations of consumers and community residents. The map should note dedications and reservations that the governing body will require in conjunction with development. Connections and required improvements to public utilities should also be indicated. The map should provide notations concerning site setback and buffer requirements along property boundaries.

Along with these site constraints, the map should reflect significant site opportunities. These should stress references to the recommendations and guidance of the community's comprehensive plan, an indication of the issues that the development program must resolve. The map should suggest potential amenities that will facilitate development and enhance project marketing. Important views, stands of trees at property boundaries, and similar characteristics should be highlighted.

Site data is also compiled in report form. The report must be well organized to present each category of information studied by the consultant. Sources of information should be clearly stated, including public officials who have been

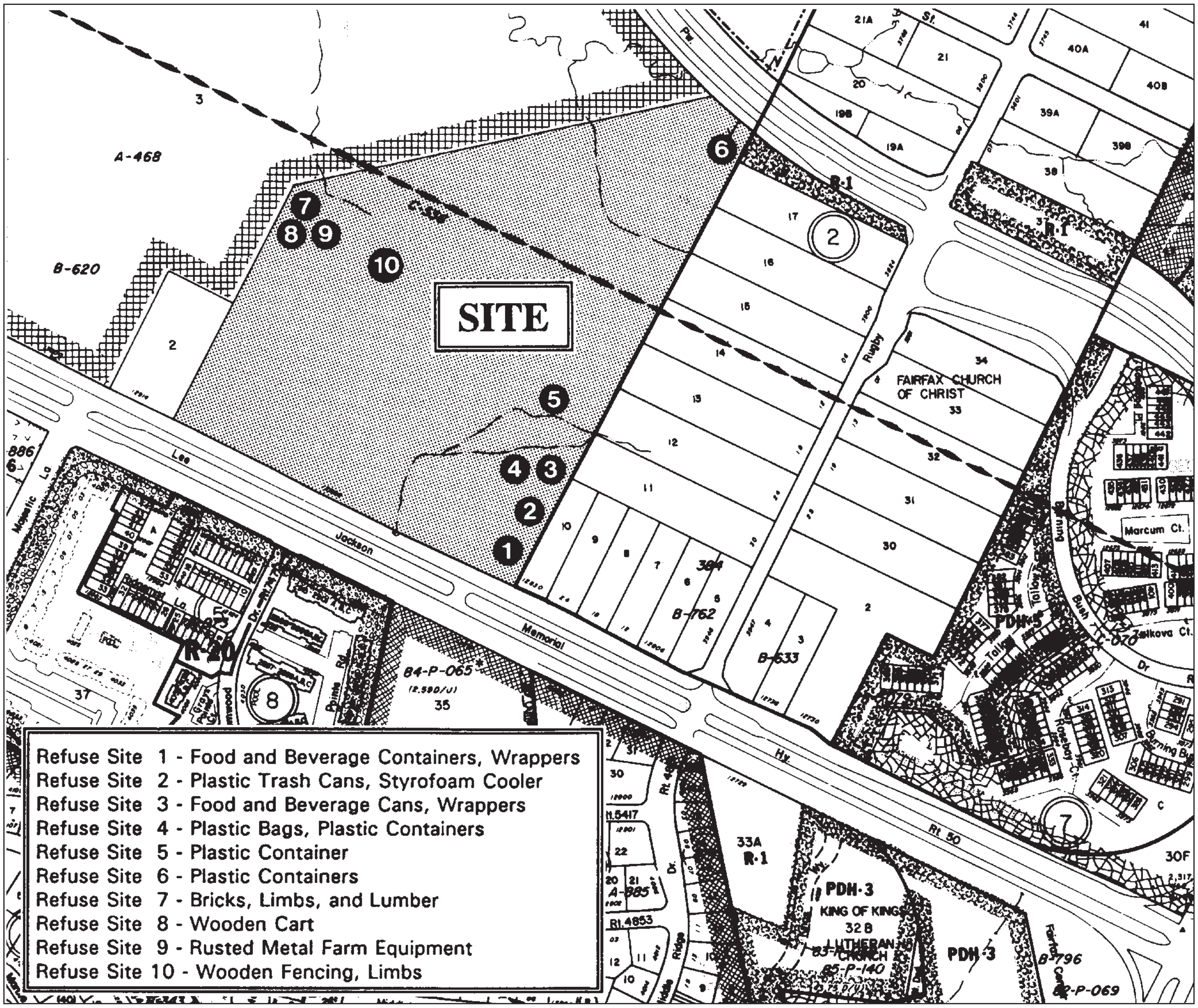

FIGURE 5.3 Site photographs cross-referenced with their location on a map often help others assess potential constraints or liabilities: (*a*) refuse site #5; (*b*) refuse site #7; (*c*) refuse site #9.

interviewed during the feasibility study. The consultant should attach copies of the comprehensive plan or zoning ordinance language that have unique and direct bearing on the project. The consultant should identify items for which administrative waivers appear appropriate and likely to be granted.

Limitations on the reliability and scope of the information should be noted. Any opinions of the consultant included in the report should be clearly identified as such. In addition, the report's findings should be qualified as being preliminary only, withholding any guarantees about potential problems that could not have been identified because of the scope or depth of study. The report will be used by the developer to determine future actions concerning the property.

The report should clearly identify qualifications to its conclusions. Sources and timeliness of information, limitations imposed by time and resources, and lack of applicability to subsequent projects should be firmly established. The report will likely serve as a reference document in further negotiations with the landowner and lender. If the developer concludes that development is feasible, the documentation is useful for those engaged to perform subsequent analysis and design. In addition, the report serves as documentation of the consultant's findings, useful in case of subsequent claims of error or omission.

Yield Study

A yield study is often performed at this stage, upon request of the developer, to determine the probable intensity of development for the property. By knowing the total development potential that can be achieved on a site, the developer can determine whether per-unit costs are within an acceptable range for local market conditions. The study will also be used as a guideline during the conceptual layout stage to

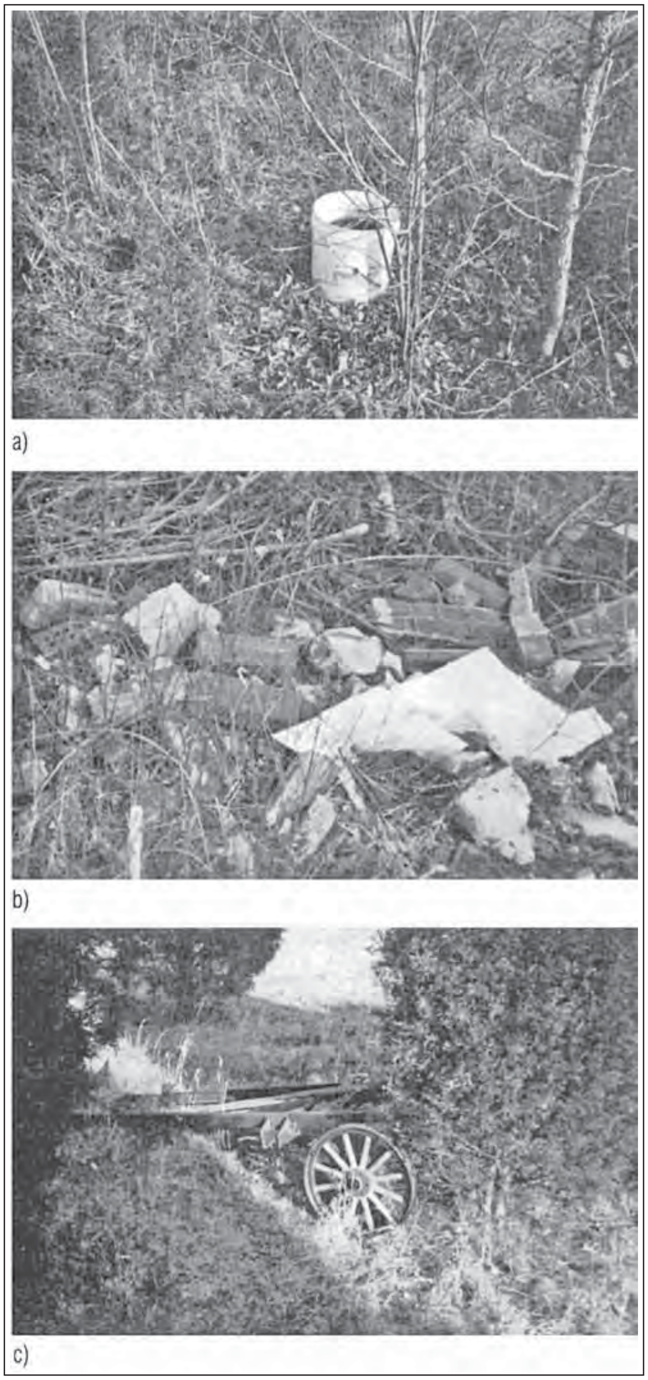

Figure 5.3 (*Continued*)

determine whether the land is being used to its greatest efficiency.

The simplest approach to a yield study is to apply maximum densities to the project area. Density of development is simply the number of new dwelling units permitted per acre of available land for residential-type development or new building area per acre of land for nonresidential development. For nonresidential development, the density is often referred to as *floor area ratio* or *building coverage* and specified as a percentage of land area. The yield study first subtracts all "uncountable" land from the gross (total) land area, to arrive at the net site area suitable for density calculation. Note the distinction between "uncountable" and "unbuildable" land. The former accounts for acreage not eligible for density calculation as defined by the local zoning ordinance. The latter is land that incorporates certain physical characteristics that cannot be corrected and that make construction impossible or impractical. For instance, most local subdivision regulations provide that floodplain land may not be built upon; some require that it be dedicated to public use. However, zoning ordinances in many of these same communities may grant the developer density credit for a portion of the land in floodplain. The uncountable land therefore *may* constitute only a percentage of the acreage to be set aside. Again, depending on local ordinance, land required for abutting street right-of-way widening or land area with terrain in excess of certain gradients *may* be excluded as uncountable land in calculating the potential yield of given acreage. Unbuildable land may include portions of a site characterized by unsuitable soils, underlying bedrock conditions, or excessive slopes, whereby simple construction economics warrant it unbuildable although the land may be eligible for density calculation from the standpoint of the local zoning ordinance.

For example, assuming a permitted density of four units per acre, a 10-acre property with 1 acre in required road right-of-way widening and 2.5 acres of floodplain may be projected to yield 26 lots in a jurisdiction that precludes right-of-way and floodplain from density calculations [(10 acres − 3.5 acres) × 4 units/acre = 26 units]. In this case, the uncountable area constitutes 3.5 acres of the 10-acre parcel. A like-size parcel with the same uncountable land area but also containing 3 acres of significant rock outcrops and slopes in excess of 30 percent (i.e., unbuildable area), while technically entitled to the same 26 lots, would, on average, require smaller lots or a different unit type to achieve a comparable yield.

In the case of residential land, the resulting net area is multiplied by the density allowed in the regulations for the proposed zoning district. For nonresidential land, total building area is derived by multiplying the countable area by the floor area ratio or building coverage permitted in the district.

The number of units derived by this method usually establishes the high end of the probable yield range. It does not account for open space, subdivision streets, stormwater management facilities, area required for off-street parking for nonresidential development, or other components of a development that occupy land to the exclusion of other uses. Other factors affect the achievement of full development potential. For instance, this approach does not reflect the practical difficulties of accommodating units precluded from unbuildable land. Characteristics of parcel size, shape, and topography also limit the number of lots or the area of new building that can be achieved. Small, irregularly shaped parcels are difficult to develop efficiently; hilly terrain also limits opportunities to maximize development potential without extensive, and expensive, clearing and grading.

A more accurate reflection of a residential site yields results by determining the total buildable area of a tract. This calculation is then adjusted to account for land that will be used for streets and other public dedication or lost to inherent inefficiencies in layout. An adjustment factor of 20 percent is reasonable. The resulting area is then divided by the lot size either allowed in the zoning district (which may be specified as a minimum or minimum average) or required by the builder (in order to accommodate the product), to arrive at probable yield. Table 5.1 is useful as a rule of thumb for estimating site yield per acre for a single-family detached development.

For greatest accuracy, and for non-single-family or nonresidential projects, a series of trial sketches prepared on an overlay of the base map is often the best approach to a yield study. This is especially important for residential projects where alternative development techniques such as clustering or transfer of development rights are possible or desirable.

Cluster development allows for reductions in lot size while maintaining the density permitted by the property's zoning. The area removed from lot development is typically preserved as open space for passive or active recreation. Quick calculation and rule-of-thumb methods assume that a conventional subdivision layout is proposed. If the local subdivision (or zoning) regulations have provisions for cluster development, a trial sketch is needed to estimate project yield. Using cluster methods, greater flexibility in street and lot layout can be achieved. This technique encourages the developer to avoid and preserve sensitive and other unbuildable areas while acknowledging that those areas are a part of the parcel and project. Using cluster provisions of the zoning or subdivision regulations, the site layout can often approach full yield while minimizing the construction of new infrastructure such as roads and utilities. Cluster allows for the recapture of units that otherwise might be lost due to unbuildable land or unusual configuration. And in some instances, local zoning regulations may even allow for a slight increase in permitted density if cluster provisions are utilized in the design of the project.

Transfer of development rights (TDR) is a realty transfer mechanism permitting landowners in areas targeted for preservation (sending areas) to separate the development rights of their property from the property itself and sell them, in the form of credits, to developers in receiving areas who then receive density bonuses for credit purchases (additional information on TDRs is included in Chapter 7). The TDR regulations will specify the allocated density bonus for each development credit purchased and the monetary cost for each credit. The TDR program may be isolated to individual municipalities or it may span regional areas such as the New Jersey Pinelands Preserve, where, for example, the purchase of 0.25 Pineland Development Credits allows an additional one unit to be included in the development of a parcel within specified Regional Growth Areas of the preserve. Although the purchase of development credits is an option open to developers for increases in density, the cost is market driven and currently ranges between $60,000 and $160,000 per full Pineland Development Credit ($15,000 to $40,000 per 0.25 credit). Several trial sketches may be necessary to determine whether the additional units gained will offset the cost of the credit(s) purchased.

For nonresidential development, yield of new building area not only is dependent on the permitted floor area ratio or building coverage, but is highly dependent on requirements for off-street parking. Local zoning regulations typically specify the size and number of parking stalls required for differing nonresidential uses, with more intense uses such as office, retail, or service establishments needing more stalls. Conversely, uses such as warehouses and industrial facilities are generally less intense and require fewer stalls. The requirements for off-street parking are typically designated per square foot of nonresidential building space, although other methods such as "per seat" or "per employee" may also be encountered. Since the number of parking stalls required is directly proportional to the amount of building area or the intensity of the development proposed, several trial sketches may be necessary to find a balance on-site that yields the maximum new building area while providing the requisite amount of parking and area for other design elements (stormwater management basins, landscape buffers, loading areas, etc.).

Trial layouts are time consuming, and the time available during the developer's feasibility option phase may be insuf-

TABLE 5.1 Estimating Single-Family Site Yield

CONVENTIONAL SUBDIVISION LAYOUT

Average lot size (ft^2)	Average yield (lots per buildable acre)
6,000–8,000	4.5
8,000–10,000	3.5
10,000–12,500	3.0
12,500–15,000	2.7
15,000–20,000	2.3
20,000–25,000	1.5
25,000–30,000	1.2
30,000–40,000	0.9
40,000–50,000	0.7

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ficient. Described fully in Chapter 11, site design, or layout, is an iterative process. However, considering a site's physical, locational, economic, and regulatory characteristics provides the developer with the most realistic assessment of a parcel's value and potential. The opportunity to consider several layouts offers an early indication of the type and form of development possible. When coupled with an early estimation of potential development costs and an evaluation of the likelihood of project approval, inclusion of trial layouts in the feasibility study is an important tool.

Estimating project yield by any method requires skills and confidence that evolve only through experience. Without that experience, both with project design and with local regulatory involvement, unrealistic estimations can result and be misleading to the developer. False estimations, at either extreme, can result in financial loss or lost opportunity. Therefore, the consultant must avoid the temptation to use shortcuts and conjecture. If the yield study is not within the scope of the services agreement with the developer, one should not be performed. In addition, site yield varies with the ability of the development team, the resources of the developer, and the market demand for a product to accommodate difficult site conditions. Thus, any yield study that is performed should be reflected as a range of units or area of new building space, specifying conditions that must be overcome during project implementation.

Because of the important role that construction costs play in project feasibility, and the impact of environmental and procedural regulation on those costs, a land development consultant should have a general understanding of construction economics. The final price of units should be weighed against the cost of acquisition, engineering, and construction. There are always several alternatives for developing the site and certain trade-offs are available. The assessment of these trade-offs requires knowledge of relative costs. In addition, certain characteristics of development projects affect market absorption, the rate at which units are sold or leased, and the period within which the developer recoups the investment. The developer bases the decision to continue or abandon the project on an estimation of costs to correct site problems. The cost analysis performed at this time will be general because of the nature of the information researched. However, it should be sufficiently detailed to enable the developer to make a well-educated decision.

The developer anticipates a certain intensity of development in order to recover costs and earn a profit. These costs include those for land acquisition and project engineering, hard construction costs for public facilities and the building product, fees, and interest-carrying charges for the land throughout the project. Using proprietary formulas that correlate investment, demand, preference, and return, the developer can evaluate finished costs, project unit size, and price range in order to recover these costs. If the projected selling price needed to recover cost is out of line with either market demand or affordability, then reevaluation of the project is needed.

If the developer concludes that the project is economically viable, he or she may elect to proceed with the development application process. The information assembled in the feasibility study is an important foundation on which to build subsequent investigation. Having identified issues for further analysis enables the consultant to assemble a team of development specialists whose expertise is specifically geared to solving problems essential to project design. Further, the consultant can develop an appropriate project work program and budget based on a clear understanding of the design requirements and an informed estimate of the labor and resources needed to resolve the issues and procure plan approval.

An Alternative Study Approach

Generally, it is *not* possible to conduct the depth and detail of analysis just described. Time constraints are frequently imposed by the dynamics of the real estate marketplace and the competitive nature of the land development industry. Decisions to move ahead must be made quickly during short purchase option periods in order to take advantage of favorable land prices or other conditions. Monetary constraints are always a factor in land development, where financial gain is likely to be several years off and cost containment is always an essential consideration. The studies described represent a considerable expenditure of funds, an up-front expense that may be incurred several times in the analysis of various sites and projects.

To provide the broadest range of services to the land developer, the land design team must learn to develop an abbreviated approach for an engineering feasibility study. Such an approach would examine the essential factors related to the development potential for a parcel of land including (at a minimum) the following:

- Identification of proper zoning or the ability to rezone
- Location and adequacy of utilities and essential services
- Access
- Topography, soils, and environmental and sensitive features—that is, defining the usable area
- Yield study to determine the amount of new units or building area possible
- Site visit

Throughout the analysis, the development team seeks to identify elements of concern, either physical or political, that suggest the land is unsuitable or that a project is not practical. The experienced consultant begins each new study with a prioritized list of items in the investigation. Through experience and frequent involvement with local land use processes and decision makers, it becomes possible to determine early in each study when the investigation should be terminated. Each consultant arrives at a level of expertise, or a comfort level, that allows relatively educated snap judgments to be made. Regardless of whether the developer then moves ahead with a particular project or abandons it, the analysis can be viewed as a justifiable expense.

Site Selection Study

Occasionally there may be several sites available with the potential to fit the development program. In such cases some process needs to be used to compare and contrast the physical and regulatory factors that affect the development program for each of the properties. This process, a site selection study, determines which property, if any, is best suited to the client's development program. In order to present the information and data collected in a fashion that allows the client to evaluate different sites without bias, a standardized narrative and graphic format needs to be developed. The site selection study involves an engineering feasibility study for each property. However, the information contained in the site selection study must be obtained in a consistent manner in order to compare the properties equally.

To determine the development opportunities and constraints associated with each property, the following site-related issues need to be reviewed:

- Property location and ownership
- Existing land use, current zoning, and master plan for the property
- Physiographic and environmental characteristics
- Order-of-magnitude development costs

Information is obtained in a similar fashion as in an engineering feasibility study for a single site: desktop review of private entity and government (federal, state, and local) resources, review of public records (either hard copies or online), site visit, relevant interviews, and other research. This information-gathering process is carried out systematically for each site in the study in order to establish consistent metrics by which to compare.

As in any engineering feasibility study, but most critically in the site selection study, the elements that are most important to the client's program need to be identified and prioritized. While many criteria have an equal weight in importance, often the land use criteria is the first reviewed. Zoning is a major factor in whether the program can be located on the property. Consideration must be given to the time necessary to amend the land use map or rezone the property if the intended use is not permitted by right. This is documented and presented to the client as the first piece of information. The time to amend a comprehensive plan or rezone a piece of property, as well as the interaction with the governing body and coordination with the citizens, may eliminate a site from consideration early in the evaluating process.

After zoning and land use issues, there are many other factors that can affect the selection of the site. In some instances site characteristics can be overcome during the development of the site. If the soils can be used for the development of the site, then grading alone can eliminate slopes, hills, and valleys to produce a desirable and functional area. However, this must be weighed against the value of the existing vegetation and habitat encompassed by the site. Grading the entire site often destroys stands of vegetation and natural habitat.

Environmental characteristics of the site also need to be determined and evaluated against the client's program. Wetlands, floodplains, and Phase I environmental assessments (ESAs) often determine the available area suitable for development. When green building certification is a project priority, the site selection study should specifically evaluate the common site location credits: Is the site located on prime farmland, habitat for threatened and endangered species, parkland, a brownfield? And what is the proximity of the site to floodplains, wetlands, natural water bodies, transit, and other developed communities? Much of this information will be available from the engineering feasibility study, but it needs to be presented in a consistent manner for comparison. A site selection study is one of the few instances where the land development consultant can help a developer make an informed decision regarding site location. While site location must be prioritized with the other selection criteria, these are important considerations, beyond just the existing physical conditions of the site, that affect the value and character of the ultimate product and should be considered as part of the decision-making process. A more detailed description of the specific green building criteria is provided within the "Environmental Impact Study" section at the conclusion of this chapter.

Capacity of the infrastructure is often the most critical factor influencing the development potential of a site, and upgrading the infrastructure can be a significant cost to the client. The major components of the infrastructure are the utilities and transportation. The availability of water, sewer, power, and telephone are usually determined in the site feasibility study, but the unique aspects of the client's program that entail special utility requirements should be assessed as a portion of the site selection study. Additional power capability for computers, dual feeds, telephone expansion, and security is an element that may need to be considered as part of the matrix. Again, these factors should be compared on a site-to-site basis.

The ability to provide adequate access to the site is also a consideration in any site selection study. Not only does the existing and proposed road network need to be considered, but also rail, bus, air, and water or any other means of transportation that might be critical to the client's program. Such access may be a part of the overall master transportation plan for the jurisdiction. While this may provide the improvements necessary for the development of the property, the timing of the improvements is crucial.

Not only are the factors that affect the development of the site important to the client, but so is the ability of the client's program to be flexible and adjust to the site. A rigid site layout or program could, by itself, eliminate a site from the selection process. The engineering feasibility study and associated yield study present the development potential of the site. A comparison between the yield study and the client's program determines the amount of adjustment, and the ensuing flexibility, required to merge the client's program to the different sites. The greater the flexibility in the program, the better the chance the program can fit a site. As stated earlier in regard to the engineering feasibility study, the cost to develop the site is a critical element in the feasibility of the site.

Not only are the development's construction costs important in a site selection study, but so are the relative construction costs associated with bringing the sites to a comparable level. If a few additional dollars need to be spent on a site (or on the infrastructure for a site) that doesn't require rezoning or any land use time, then this may be less expensive than the time it would take to go through the planning process. While the client doesn't often own the property until it is zoned and doesn't have a great carrying cost on the land loan, rezoning is still a time-consuming process that results in a lost (or delayed) opportunity to make money on the project. In some cases the site selection study may establish a criterion for site availability. Is the site available now or are there steps and time required before development can begin? In this case, the only way to make the site immediately available may be through spending some money to make it acceptable as an element of review. Money may have to be spent to improve the access or provide utilities and thus avoid having to go through the time-consuming rezoning process.

Once all the data is collected, a value or rank is assigned to each factor. A matrix can then be used to collectively show the information and evaluate each property. An example of the procedure is shown in Tables 5.2 and 5.3. Table 5.2 lists the criteria pertinent to one particular development program. The type of shading of the boxes indicates the basic differences of each item. Each potential tract of land is then evaluated based on the listed criteria. Table 5.3 is a compilation of the criteria for each alternative site. Selecting the property best suited for the program is ultimately a business decision for the client. Each item does not necessarily have equal weight in importance or priority, and only the client knows what the relative weight of the items are in terms of his best interests or situation. The land design consultant supplies the data for the client to analyze to make the selection.

TABLE 5.2 Criteria and Values for Elements of the Site Selection Study

Planning Criteria	
Existing zone	■ Zoned for intended use
	◩ Zoned for nonresidential use
	□ Zoned for agricultural/residential
Adjacent land use	■ Adjacent uses office/mixed use
	◩ Adjacent uses nonresidential
	□ Adjacent uses agricultural/residential
Consistency with comprehensive plans	■ Specific use consistent with comprehensive plan
	◩ General use consistent with comprehensive plan
	□ Use not consistent with comprehensive plan
Site Characteristics	
Topography	■ Relatively flat site <5%
	◩ Moderate slope constraints 5–15%
	□ Significant slope constraints >15%
Drainage	■ Single drainage shed
	◩ Several drainage sheds
	□ Numerous drainage sheds
Soils/Substances	■ Minimum grading/excavation problems anticipated
	◩ Moderate grading/excavation problems anticipated
	□ Significant grading/excavation problems anticipated
Vegetation	■ Significant native vegetation for landscape buffer/character
	◩ Moderate native vegetation for landscape buffer/character
	□ No native vegetation for landscape buffer/character
Structures	■ No existing on-site structures
	◩ Existing structures of marginal value/concern
	□ Existing structures of significant value/concern

(*Continued*)

TABLE 5.2 Criteria and Values for Elements of the Site Selection Study (*Continued*)

ENVIRONMENTAL CHARACTERISTICS	
Wetlands	■ Minimum wetlands constraints (*approx. less than 1 acre of care area*) ◩ Moderate wetlands constraints (*approx. between 1 and 10 acres of care area*) □ Significant wetlands constraints (*approx. more than 10 acres of care area*)
Floodplain	■ No floodplain ◩ Floodplain but no impact on care development area □ Floodplain within care development area
INFRASTRUCTURE—UTILITIES	
Power Water supply Sanitary sewer Communications Natural gas}	■ Available capacity on-site or immediate proximity ◩ Available in general vicinity □ Capacity not available in general vicinity
INFRASTRUCTURE—TRANSPORTATION	
Existing roads	■ Two or more existing roads available to access/egress site and major regional arterial/freeway in close proximity ◩ Two or more existing roads available to access/egress site □ One existing road available to access/egress site
Site access	■ No encumbrances to two points of access/egress ◩ Limited encumbrances to two points of access/egress □ Both access/egress points significantly encumbered
Proposed roads	■ Multiple master planned or existing roads adjacent to core development area and regional arterial/freeway in close proximity ◩ Two master planned roads or existing road adjacent to care development area □ One master planned road or existing road adjacent to care development area
Mass transit	■ Rail and bus available ◩ Bus available □ No mass transit available
Rail	■ Rail line immediately adjacent to site ◩ Rail line in general vicinity □ No rail line in general vicinity
Flight paths	■ No flight path near site ◩ Flight path near site flight altitude restrictions □ Flight path nearby and low altitude
PROGRAM FIT	
	■ Program fits/additional acreage provides location flexibility ◩ Program fits/limited location flexibility □ Program does not fit
R.O.M.* COSTS	
	■ Excessive or unusual cases ◩ Ranking 1 through 9, low cost to high cost □ N/A—nonapplicable

*Rough order of magnitude

TABLE 5.3 Matrix Comparison of Properties

	ALTERNATE SITES								
CRITERIA	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**
Planning criteria									
Existing zoning	◩	◩	◩	◩	◩	■	□	□	□
Adjacent land use	■	■	■	■	◩	◩	□	□	◩
Consistency with comprehensive plans	◩	■	◩	□	□	■	□	□	◩
Site characteristics									
Topography	■	◩	◩	◩	■	■	■	□	■
Drainage	◩	□	◩	◩	■	■	◩	◩	◩
Soils/subsurface	◩	◩	◩	□	◩	◩	■	□	■
Vegetation	□	■	◩	■	■	◩	◩	◩	◩
Structure	◩	□	□	◩	◩	◩	◩	◩	◩
Environmental characteristics									
Wetlands	◩	◩	◩	◩	■	◩	■	◩	■
Floodplain	◩	◩	□	◩	□	■	◩	□	◩
Infrastructure—utilities									
Power	◩	■	◩	□	◩	□	□	□	◩
Water supply	■	■	■	◩	◩	■	□	□	◩
Sanitary sewer	■	◩	◩	◩	◩	■	□	□	◩
Communications	◩	◩	◩	◩	◩	□	□	◩	◩
Natural gas	■	■	■	□	□	■	□	■	□
Infrastructure—transportation									
Existing roads	■	■	■	□	◩	■	□	◩	◩
Site access	■	■	■	■	■	■	◩	□	■
Proposed roads	■	■	■	◩	◩	■	□	□	□
Mass transit	□	□	□	□	□	□	□	□	■
Rail	□	□	□	□	□	□	□	□	■
Flight paths	◩	◩	□	◩	□	■	■	□	□
Program fit	■	■	□	◩	■	■	■	■	■
R.O.M.* costs (ranked; #1 = lowest cost)	3	4	N/A	6	1	5	7	8	2

*Rough order of magnitude.

OTHER IMPACT STUDIES

Other studies may be required by the local governing body to determine the impact of the proposed development on the community, environment, or public infrastructure. These typically are performed after the proposed use and development plan has progressed toward its final stages. However, in many cases, the outputs from these studies are considered during development applications to determine the appropriateness of the use or intensity. Often, they are used to determine appropriate dedications or improvements, assessment of impact, or similar fees or to set a timetable for the staging of development.

Land development specialists other than the design consultants often perform these studies. However, they are mentioned here because many of the data inputs collected for the feasibility study are used in subsequent analysis. In addition, the outcome of these studies could affect project feasibility and further design efforts. This is especially true where known constraints in public systems or issues of community priority may have direct bearing on the use and yield of development sites.

Traffic Impact Study

Traffic studies often are required as part of the submittal package for a rezoning or special exception application. They serve two primary purposes. The first is to identify potential impacts of the proposal on the transportation system in the general area of the development. Second, the study looks specifically at potential impacts on roads and intersections in the immediate vicinity of the project. In communities that assess impact fees on development or operate under an adequate public facilities ordinance, a traffic study may be required for subdivision and building permit approval as well.

In addition to its review in consideration of project approval, the results of the traffic study serve to indicate system improvements to mitigate project impact. For instance, the need for additional right-of-way for road widening or turn lanes may be a consequence of the study. This may affect project yield by encumbering otherwise developable land. The local governing body also may use the study to support operating restrictions on certain uses to increase the efficiency of the existing system.

The traffic study consists of four basic elements:

1. System capacity and level of service analysis

2. Background traffic assessment, an analysis of existing traffic that also considers traffic generated by pending projects and potential projects for which rezoning approval is not required

3. Projected traffic generation for the proposed development, including probable origins or destinations and modes of transportation

4. Analysis of adjoining roads and nearby intersections to determine need for right-of-way or pavement widening, turn lane improvements, and traffic control signs or signalization

Depending on the nature of the project, its location relative to the transportation network, and other factors, a traffic study would include data such as current daily traffic volumes, existing peak-hour turning volumes, estimated site traffic generation, directional distribution of site traffic, estimated trip generation for nonsite development, estimated total future traffic, and projected levels of service. Part of the street design, such as number of lanes, turn lanes, and intersection control, would be based on this data. Figure 5.4 is an example from a traffic study showing the impact of a new project on the traffic.

The traffic study typically projects the volume for four types of traffic:

1. *Existing traffic:* Volume of traffic vehicles that are using the road prior to improvements and modifications.

2. *Future background traffic:* Increase in traffic expected to occur at the time of development (not including traffic generated by new development).

3. *Site traffic:* Traffic explicitly generated by new development project.

4. *Total future traffic:* Sum of the future background traffic and site traffic.

Traffic volume is a result of traffic demand. Land use, socioeconomic conditions, and the amount and type of available transportation affect travel demand. Land use dictates the location and intensity of the activity, and socioeconomic factors determine the magnitude and extent of population activity. The two factors are integral components in the development of trip generation models.

Trip generation models predict how many trips each activity produces and the origin and destination of such trips. Forecasting travel demand with elaborate trip generation models or with tables, such as Table 5.4, depends on the level of detail required for the study. The travel demand analysis is a key element of transportation planning, whether for long-range wide-area comprehensive plans or for short-range plans for a traffic corridor or specific project.

Methods used for estimating traffic volumes on local and collector residential streets may be different than those used for streets higher in the functional hierarchy or for commercial/industrial projects. Whereas the higher-order streets require detailed traffic analysis and future traffic volume projections, volumes on residential streets are typically based on averages of vehicle trips per type of dwelling unit. Table 5.4 provides estimates on the number of trips generated for various land uses.

The trip rates shown in Table 5.4 are trip-ends. A *trip-end* is "a single or one direction vehicle movement with either the origin or destination (exiting or entering) inside a study site."[2] For example, a person leaving home for work and returning later in the day constitutes *two* trip-ends for that dwelling unit. The *Trip Generation* manual contains trip rates for nearly every type of land use. Readers should refer to this manual to estimate trip generation in more specific detail.

Two parameters frequently referred to in the design of major roads are the *average daily traffic* (ADT) and *design hourly volume* (DHV). The ADT is the traffic volume counted over a number of 24-hour periods divided by the number of 24-hour periods. The ADT is a parameter used to measure and evaluate existing traffic flow and plan for future roads. ADT volumes do not reflect the specific variation in volumes during peak hours. Design for the expected greatest peak volume would not be cost effective. Therefore a cost-effective design must be one based on a traffic volume that may be only occasionally exceeded.

The DHV is the projected hourly volume used for setting the geometric design. It provides a base to account for change in demand on a roadway over a projected design period. Data collected from rural arterial streets for a wide range of traffic volumes over a wide geographic area has shown that there are approximately 30 hours in a year when the road carries the highest hourly volume (HV). The traffic volume for the remaining hours of the year is nearly uniform relative to the 30 highest hours. Based on these results the thirtieth highest hourly volume for the projected design year

[2] *Trip Generation,* 5th ed. 1991. Washington, DC: Institute of Transportation Engineers.

TABLE 5.4 Weekday Vehicle Trip Generation for Selected Land Uses (given as trip-ends)

Single-family detached		9.6/DU
Residential planned unit development		7.5/DU
Residential condominium/town house		5.9/DU
Apartment		6.7/DU
Mobile home park		5.0/DU
General office building	11.0/1000 ft^2	
Shopping center (excluding Christmas season)	42.9/1000 ft^2	
Business park	12.8/1000 ft^2	
Industrial park per employee		3.3/employee
County park		3.0/acre

(Compiled from ITE's *Trip Generation,* 7th ed.)

is determined as the DHV. That is to say that the projected hourly volume of traffic will be greater than the DHV only 29 hours in the year. In urban areas the thirtieth HV is typically selected as the DHV as a general rule. However, unique land use and other special situations such as major seasonal recreation areas may warrant deviations from this general rule. In many instances the DHV is taken as a percentage of the ADT. On urban highways the DHV is normally between 8 percent and 12 percent of the ADT.

Traffic volumes are necessary to determine the impact a development project has on existing streets. New development generates more traffic and consequently may alter prevailing traffic patterns. Traffic volumes fluctuate daily and seasonally depending on the area served by the street. Major corridors serving commercial and business areas have peak volumes in morning and late afternoons. Retail areas have peak volumes on weekends and evenings, especially during holidays. Many local agencies require off-site construction or financial contributions to alleviate the impact of development on nearby collector and arterial streets. Transportation impact studies for various types of land development projects above a certain size, when required, are normally performed by traffic engineering consultants.

Community Impact Study

In communities experiencing significant growth, local regulations may require analysis of the potential impacts new development may have on the entire community. Focus on anticipated population growth, available capacity of existing utilities, adequacy of municipal facilities and services, and demand on schools is typically required. Demonstration that existing public facilities such as community centers and libraries and municipal services such as police and fire protection, emergency response, hospital and health care, solid waste disposal, and public works will be able to accommodate the increase in population generated by new development is necessary. Otherwise, the developer may be required to provide monetary contributions to the municipality for improvements to those facilities and services adversely impacted. In some instances, the developer may even be required to fund and construct new facilities or provide improvements to existing facilities to accommodate the new demands.

In most municipalities where schools are directly funded from local property taxes, potential overcrowding in classrooms is of the most importance. The ability to develop a site may often be jeopardized where project approval depends on available capacity within the local school system or the magnitude of the additional tax burden generated by the increase in the number of pupils. The development application may include requirements for a pupil generation study to be performed by the development team. This examines the impact on the public school system by the new development. Through the analysis, the developer may be able to demonstrate that because of characteristics peculiar to the project, demand for available capacity may be less than anticipated. Many communities recognize that factors such as housing type and bedroom count have direct correlation to the number of school-age students who will occupy a development. In addition, developments geared to older single-person households are likely to generate few students, even if age restriction is not a factor or is prohibited by law. Rather than accept standard local housing unit/pupil ratios, the developer may have the option of surveying similar developments in the community. With this study, it may be possible to demonstrate that the probable impact of the project on student population is lower than originally suggested.

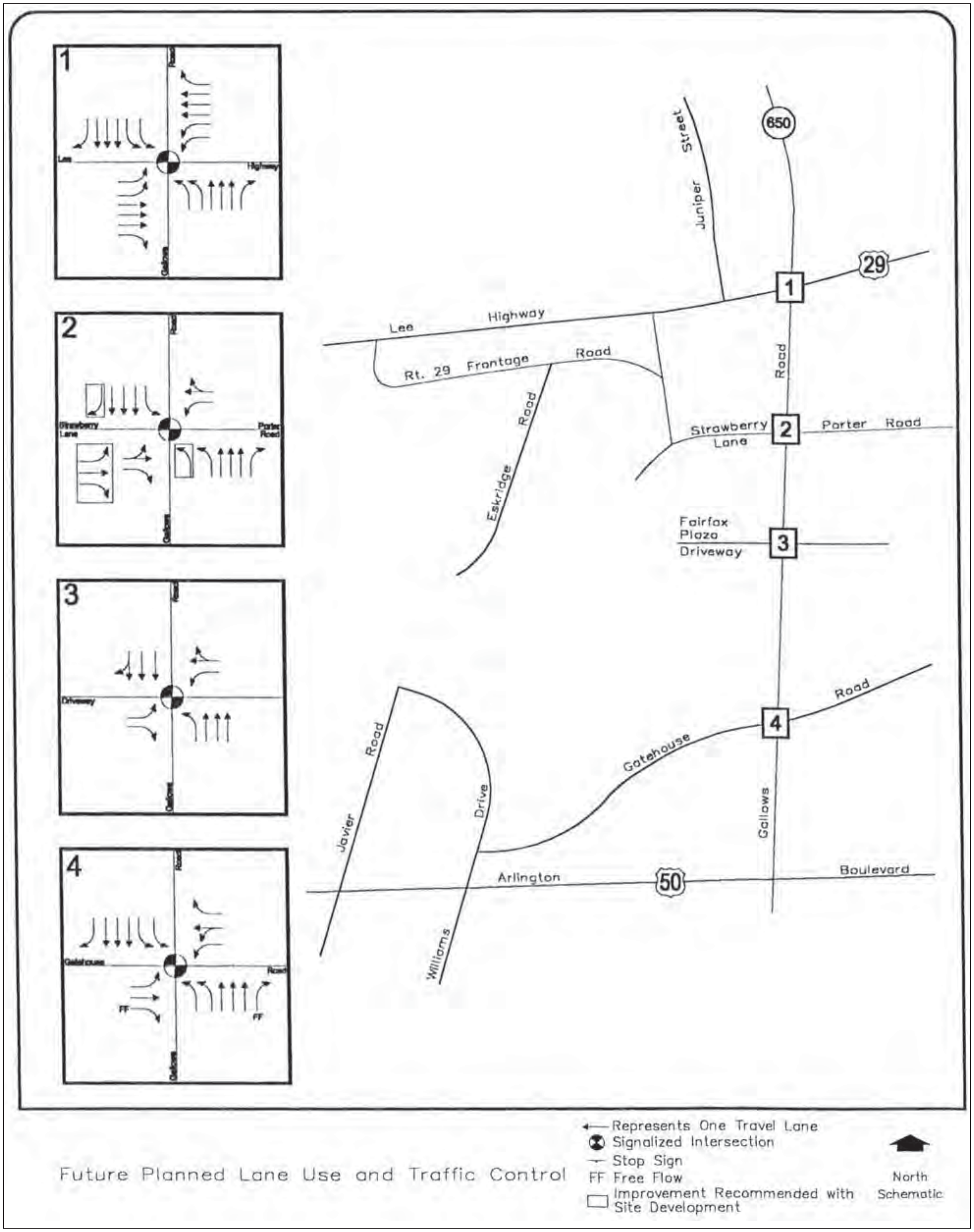

FIGURE 5.4 Traffic study—Merrifield Town Center. (Courtesy of Wells + Associates, Inc., McLean, VA)

Fiscal Impact Study

A determination as to whether the local municipality can expect sufficient tax revenue from the project to offset the costs from the impacts reviewed during preparation of the community impact study may be necessary. This fiscal impact study is typically required as part of the submittal for local approval of the project, but it may be commissioned by the developer prior to full design to evaluate financial impacts on the affected municipality.

In general, analysis of the fiscal impact of a project begins by applying the current tax rate within the municipality (available from public records) to the anticipated cost of new dwelling units or building area to calculate the total amount of tax revenue generated. Existing census data is then utilized to project the number of expected residents and pupils from the development. By applying the total tax revenue generated to the projected number of residents, the expected per capita tax revenue from the development is determined.

An evaluation of the actual current per capita costs to existing residents for municipal and school services is then performed. This cost is calculated by simply applying the most current municipal and school budgets, which are available through public records, to the population estimate from the latest census data or other available records.

If the expected tax revenue per capita is more than the actual, then a positive impact from the development has been demonstrated. For those instances where a negative impact is calculated, the local municipality may require the developer to provide contributions for improvements to municipal services or even new facilities. Knowing the magnitude of potential municipal improvement costs during the early stages of the project is an important factor utilized by the developer in determining the project's economic feasibility.

Environmental Impact Study

As referenced in the preceding chapters, significant amounts of effort and diligence are expended to evaluate and assess the existing environmental conditions of a site, including the presence of environmentally sensitive areas, contaminated areas, threatened and endangered species, prime agricultural land, and historic/archaeological features. An environmental impact study[3] summarizes the impact the proposed development might have on these areas and other areas of concern, which typically include air quality, surface water and ground water quality, geology, soils, aesthetics, and noise. Data gathered during the engineering feasibility study can be used in concert with the information obtained in the environmental assessment to prepare a thorough study in which the environmental impacts are qualified, quantified, and assessed in terms of avoidance, minimization, and mitigation strategies and permitting requirements.

[3]In this chapter, *environmental impact study* refers to an initial assessment for the purposes of the client's feasibility decision-making process and does not refer to the more formal, federally regulated NEPA EIS.

Green Building and Sustainable Design. When considering the environmental impact of a particular development, it should be determined during the initial planning stages whether the project (client) is seeking a third-party green building certification or if compliance with green building design guidelines is mandated by federal, state, or local regulations. Whether a client priority or jurisdictional requirement, green building design guidelines are widely accepted and highly regarded within the land development profession as sound planning strategies. As such, they should be referred to throughout the land development process as a design tool, regardless of the need for third-party certification.

Several organizations currently provide green building design guidelines and third-party evaluation/certification of designs in accordance with their respective criteria or rating system:

- U.S. Green Building Council (USGBC)—Leadership in Energy and Environmental Design (LEED) Rating Systems
- National Association of Homebuilders (NAHB)—Model Green Home Building Guidelines
- Green Building Initiative (GBI)—Green Globes
- National Institute of Building Sciences—Whole Building Design Guide
- Enterprise Community Partners—Green Communities
- Building Research Establishment (BRE) Limited—Environmental Assessment Method (BREEAM)
- New York City—High Performance Infrastructure Guidelines

The USGBC—LEED program is currently the most common green building rating system and as such is discussed in more detail throughout this text. The USGBC offers several different green building rating systems covering nearly every market sector of the land development industry, including New Construction and Major Renovations (NC), Existing Buildings (EB), Commercial Interiors (CI), Core and Shell (CS), and Schools (S). Other programs in pilot form at the date of this printing include rating systems for Homes, Neighborhood Development (ND), and Retail—New Construction. Additional rating systems for Healthcare and Laboratories are also in the initial stages of development. Selection of the appropriate design guidelines and rating system is dependent on the type of development proposed, jurisdictional requirements, and owner/developer priorities. The land development consultant should be familiar with the various third-party certifying entities and their rating systems or guidelines in order to advise clients appropriately for their specific application.

Each site and building is different, and the green building guidelines, in their various forms, seek to accommodate this uniqueness while still ultimately producing a sustainable project. To obtain LEED certification, a development must obtain a minimum amount of points or credits as prescribed in the applicable rating system in addition to all prerequisites. Additional levels of certification—such as silver, gold, and platinum, corresponding to increasing levels of sustainability or environmentally friendly design—can be achieved by accumulating credits above the minimum necessary for certification.

For residential and general land development as outlined within this book, the appropriate rating system is that established for New Construction and Major Renovations (NC).[4] Under the LEED—NC rating system,[5] projects are evaluated on the basis of six major categories: (1) Sustainable Sites, (2) Water Efficiency, (3) Energy and Atmosphere, (4) Materials and Resources, (5) Indoor Environmental Quality, and (6) Innovation and Design. Within each category, credits are awarded for demonstrating compliance with the criteria listed. For land development consultants, the focus lies within the Sustainable Sites (SS) category, where a credit is received for compliance with each of the following guidelines:

Prerequisite: Construction Activity Pollution Prevention Plan

1 Site Selection

2 Development Density and Community Connectivity

3 Brownfield Redevelopment

4.1 Alternative Transportation: Public Transportation Access

4.2 Alternative Transportation: Bicycle Storage and Changing Rooms

4.3 Alternative Transportation: Low Emitting and Fuel Efficient Vehicles

4.4 Alternative Transportation: Parking Capacity

5.1 Site Development: Protect or Restore Habitat

5.2 Site Development: Maximize Open Space

6.1 Stormwater Design: Quantity Control

6.2 Stormwater Design: Quality Control

7.1 Heat Island Effect: Non-Roof

7.2 Heat Island Effect: Roof

8 Light Pollution Reduction

Beyond the Sustainable Site category of LEED—NC, the land development consultant may also influence the credits within the Water Efficiency section, specifically those credits related to landscaping (WE 1.1 and 1.2) and wastewater treatment (WE 2). While the other categories tend to be very building (architecture) oriented, the land development consultant should still be attuned to these credits, as system integration is inevitable and must be coordinated. Further, even the very basic decisions regarding site location, site layout, and building orientation can greatly affect the building systems and their efficient function. Many projects now have one, if not more, LEED Accredited Professionals (LEED APs) as members of the design team in order to facilitate a more integrated design process including educating team members about the credit intents and requirements and documenting the design effort in a manner conducive to certifying the project.

Knowing the established criteria, determination should be made by the design team, with input from the client/developer, of the desired green building design goals for the project. Care should then be taken during preparation of the engineering feasibility study and environmental impact study to include evaluation of the characteristics of the site that do or do not comply with the criteria of the applicable rating system and the established goals. A generalized process for incorporating green building techniques into the land development design process is shown in Table 5.5.

During engineering feasibility, primary attention should remain on evaluating the site(s) with respect to the criteria for Credits 1, 2, 3, and 4.1, as these credits deal solely with existing site conditions and location. For item 1, Site Selection, credit is awarded for development that is not located on:

- Prime farmland as defined by the USDA
- Previously undeveloped land whose elevation is lower than 5 feet above the elevation of the 100-year floodplain as defined by FEMA
- Land that is specifically identified as habitat for any species found on the federal or state threatened and endangered lists
- Land within 100 feet of any wetlands or designated wetlands buffers
- Previously undeveloped land that is within 50 feet of a water body that supports or could support fish, recreation, or industrial use consistent with the Clean Water Act
- Land that is public parkland

Compliance with item 2, Development Density and Community Connectivity, can be demonstrated by developing a site within proximity of other developed areas and that is accessible (by pedestrians) to basic community services. Item 3, Brownfield Redevelopment, stipulates development on a site documented as contaminated by a local, state, or

[4]In the future, the LEED for Neighborhood Development (ND) system will be most applicable to the land development consultant, as it deals with community design development at the same scale as in this book. However, it is still in pilot form and subject to change. Thus, for purposes of this text, green building discussion will be framed around the LEED—NC system, particularly the Sustainable Sites category. Note that every green building rating system has a site component, and many of the metrics are similar to those of the LEED—NC system.

[5]The full LEED—NC checklist is included in Appendix G of this text.

<table>
<caption>TABLE 5.5 Integrating Sustainability into the Land Development Design Process</caption>
<tr><th>Design Phase</th><th>Action</th><th></th></tr>
<tr><td>Feasibility & Site Analysis</td><td>Establish Goals, Identify Constraints and Opportunities</td><td rowspan="7">Document</td></tr>
<tr><td>Concept Design</td><td>Think Big, Innovate and Develop Sustainable Design Strategies</td></tr>
<tr><td>Schematic Design</td><td>Refine Goals, Implement Design Strategies, Build Baseline Models</td></tr>
<tr><td>Final Design</td><td>Integrate and Detail Design Strategies in Construction Plans and Specifications</td></tr>
<tr><td>Plan Approval/Permitting</td><td>Submit for Certification, Revise as necessary</td></tr>
<tr><td>Construction</td><td>Follow Through and Coordinate with contractor</td></tr>
<tr><td>Postconstruction</td><td>Monitor and Maintain Sustainable Systems; Train/Educate Users</td></tr>
</table>

federal agency; item 4.1 requires that the project site be located within proximity of commuter rail, light rail, subway station, or public bus lines.

By considering the applicable rating system criteria during the initial stages of site planning, such as the engineering feasibility phase, projects can more easily reach the desired green building goals by simply selecting sites that meet all or some of the existing location and condition criteria previously discussed. The design team will also have the opportunity early on to determine whether some of the noncompliant characteristics of the selected site can be overcome by incorporating techniques for sustainable development into the project design, thereby gaining credits necessary for achieving the preferred level of certification. The specific criteria for the Sustainable Sites prerequisite and credits 4.2 through 8 of the LEED—NC rating system and methods for compliance with these design-related guidelines are discussed in subsequent chapters of this book.

EXAMPLE OF A PRELIMINARY FEASIBILITY STUDY

Preliminary Engineering Feasibility Study
January 1992

TRACT LOCATION

The subject site consists of approximately 30 acres and is located in the Sully District of Fairfax County, Virginia. The site is identified on the Fairfax County Tax Map as 45-2 ((1)) part of parcel 1. The property is bordered by the Lee-Jackson Memorial Highway (Route 50) to the south, the Murray Farms Subdivision to the east, the Fairfax County Parkway (Route 7100) to the northeast, and undeveloped property to the north and west. The mailing address for the subject site is 12908 Lee-Jackson Memorial Highway, Fairfax, Virginia 22033.

ZONING/COMPREHENSIVE PLAN

The study area is in the UPS Lee-Jackson Planning Sector of the Upper Potomac Planning District in Area III of the Fairfax County Comprehensive Plan. The property is currently zoned R-1; low density residential use not to exceed one dwelling unit per acre. The Comprehensive Plan recommends low to medium residential use at two to three dwelling units per acre. The Plan further states that ". . . Complete consolidation of Parcels 1, 2, and 3 is a condition for consideration of the high end of the Plan range, three dwelling units per acre." The portion of the Murray Farms subdivision located immediately east of the subject parcel and south of the Fairfax County Parkway is planned for a residential use at one to two dwelling units per acre. The Plan provides an optional density of four to five dwelling units per acre for this area if all the land is consolidated. Please refer to Attached 1, Zoning Map.

The Fairfax County Zoning Ordinance permits the establishment of golf driving ranges and commercial golf courses in the R-1 District with the approval of a Group 6 Special Permit by the Board of Zoning Appeals. Included as Appendix #1 is a copy of a portion of Part 6 of Article 8 of the Zoning Ordinance which specifies the standards for all Group 6 uses as well as the additional standards applicable to golf courses and golf driving ranges.

The process for a Special Permit application takes approximately 90 days from the date the application is accepted by Fairfax County. State statute requires action by the Board of Zoning Appeals within 90 days unless the applicant agrees to a deferral beyond the 90 days period. The timeframe for the actual preparation of the Special Permit Plat will be dependent upon the receipt of a conceptual design of the facility by your golf course consultant. Once that information is received, the Plat can be prepared in approximately ten (10) working days.

UTILITY AVAILABILITY

Water: The subject site is located in the Fairfax County Water Authority (FCWA) service area. According to Mr. Don Hume of FCWA, there are two water mains which could serve the subject site: (1) A 14-inch water main located along the south side of Route 50, and (2) A 12-inch water main located along the north side of Route 50 approximately 450 feet east of the site. Please refer to Attachment #2, Water Availability Map.

Connecting to the existing 12-inch water main would require boring under the roadway for approximately 200 feet. An eight-inch water main within a 20-inch casing would be required. The second alternative would require the extension of a 12-inch water main approximately 1,000 feet from the existing terminus to the subject site. Preliminary calculations include that either option would cost approximately $50,000 to $55,000.

It appears that no offsite easements would be required with either water service alternative since all connections and extensions would be within the Virginia Department of Transportation (VDOT) right-of-way.

Mr. Hume stated that further analysis by FCWA will be required in order to confirm exact line size requirements and to determine which alignment option may best benefit the developer and FCWA.

Sanitary Sewer: The subject site is located in Subshed T-2 of the Cub Run Sanitary Sewer service area. According to Mr. Jerry Jackson of the Fairfax County Department of Public Works (DPW), sanitary sewer service is not readily available to the site. Although sanitary sewer service is available for the townhouse and garden apartment development immediately south of Route 50, Mr. Jackson stated that a majority of the subject site is in a different drainage shed and cannot be sewered by gravity flow to this location. The closest available sewer by gravity flow is a 12-inch line approximately 2,100 feet northwest of the property. Please refer to Attachment #3, Sanitary Sewer Availability Map.

This existing sanitary sewer, which is within the International Town and Country Club property, was designed to accommodate flows from the subject site at a proposed density of two dwelling units per acre (current Comprehensive Plan density). Mr. Jackson stated that approximately 12 units of the subject site, which naturally drains south across Route 50, could be developed so that sewer would be diverted to the northwest. Given the topography of the site, the diverted sewer system should be able to cross the natural drainage divide at a depth less than the allowable maximum of 16 feet. Mr. Jackson stated that this would be the alignment preferred by DPW. A 10-foot-wide offsite sanitary sewer easement would be required from the owners of the adjacent Parcel 3 and the International Town and Country Club in order to construct the required eight-inch sanitary sewer line.

The Fairfax County Health Department was contacted for information regarding the septic system used for the residence on the subject property. The Health Department has not approved septic field plans or records for the property. Conversations with the owners have determined that the septic field is located in the southwest portion of the property behind the garage. The system was constructed approximately 25 to 30 years ago.

A preliminary soils study, including test borings and other field observations, was conducted by Soil Tech, Inc. Preliminary findings indicate that there are two areas suitable for conventional septic drain fields: (1) The southwest portion of the property immediately behind the onsite structures, and (2) the southeast portion of the property near Route 50. These areas appear to be capable of processing from 600 to 1,800 gallons of waste water per day. This would equate to a commercial/office establishment with 20 to 60 employees. Additional areas may be suitable for more progressive systems such as elevated sand mounds. It should be noted that additional studies and Fairfax County Health Department approval will be required before the drain field locations and types can be finalized.

TRANSPORTATION/ACCESS REQUIREMENTS

The more logical location for access along Route 50 appears to be opposite the median break near the southeast corner of the subject site. Based upon Fairfax County topography, this location does not appear to present any horizontal or vertical sight distance problems; however, this location would still need to be approved by the Fairfax County Office of Transportation (OT) and the Virginia Department of Transportation (VDOT).

Route 50 is designated on the Comprehensive Plan as a six-lane divided facility. According to a spokesperson from OT, the following transportation improvements would be requested/required for the development of this property:

- Construction of a third through lane for westbound Route 50 or a monetary contribution for construction avoidance,
- Construction of a left-turn lane into the site from eastbound Route 50,
- Construction of a right-turn lane into the site from westbound Route 50, and
- Construction of a service drive along the property's frontage unless a waiver can be obtained during the zoning process.

Additional development conditions may be imposed as the special permit application is reviewed by the appropriate State and County agencies.

It should be noted that Route 50 is currently being improved from Townwood Drive west to Plaza Lane. This construction is being funded by a developer in conjunction with the expansion of Greenbriar Shopping Center. According to a spokesperson from VDOT, this project involves the construction of dual left turn lanes for westbound Route 50 into Majestic Lane, Plaza Lane and the shopping center entrance. Service drive improvements are also being constructed.

SITE CHARACTERISTICS/TOPOGRAPHY

The subject site contains five structures, all of which are located in the southwestern portion of the property. These structures include:

- A one-story wood-framed residence with basement and attic;
- A wood-framed two-car garage; and
- Three wood-framed out buildings, evidently used for the storage of farm equipment and tools.

The entire property remains relatively clear of mature vegetation; although cedar trees of three to six feet in height are beginning to overtake a large portion of the property. Overhead electric and telephone lines, which serve the onsite residence, extend along the site's Route 50 frontage for approximately 400 feet. A concrete drainage ditch also extends along the site's Route 50 frontage for approximately 800 feet. This ditch drains into a 48-inch culvert which extends under Route 50 towards the Grays Point subdivision.

Onsite elevations vary from a high point of approximately 388.2 at the property's southwest corner to a low point of approximately 370.0 at the property's northwest corner where a swale exits the property. Onsite slopes are generally mild and primarily range from 1% to 10%. A small area of slopes in excess of 15% is located along the northern property line. Please refer to Attachment #4, Topography Map.

The property contains three pronounced swales which convey stormwater runoff through the subject site. These swales are not identified on the U.S. Geological Survey Quadrangle Map (Herndon) as either perennial or intermittent streams; therefore, minimal water flow is probably only apparent during storm events. However, during the field investigation conducted January 7, 1992, standing water was apparent in all three swales. For a more detailed discussion of stormwater runoff and onsite drainage patterns, please refer to the section entitled "Stormwater Management Requirements."

SOILS

The Fairfax County Soils Survey was reviewed for preliminary geotechnical information. The soils survey indicates that the subject site is comprised of the following soil types:

Soil Number	Soil Name	Percentage of Site
1	Mixed Alluvial	1% ±
14	Manassas	7% ±
67	Penn FSL	41% ±
72	Bucks (L)	<15 ±
76	Calverton (L)	16% ±
80	Croton	30% ±
273	Readington	4% ±

Please refer to Attachment #5, Soils Map.

General ratings for development within these soil types can be summarized as follows:

Soil Name	Subsurface Drainage	Foundation Support	Slope Stability	Problem Class
Mixed Alluvial	Poor	Poor	Good	A
Manassas	Marginal	Fair	Good	B
Penn	Fair	Good	Good	C
Bucks	Good	Good	Good	C
Calverton	Marginal	Poor	Good	A
Croton	Poor	Poor	Good	A
Readington	Marginal	Good	Good	B

A geotechnical engineering report is mandatory for all construction and grading within Group A Soils, i.e. the Mixed Alluvial, Calverton and Croton soils. Some of the characteristics which are typical of soils within this problem class include:

- Flooding hazards following storm events,
- Low bearing values for foundation supports,
- High seasonal ground water tables in drainage ways or low-lying areas,
- Moderate to high shrink-swell potential often having slow to very slow permeability rates, and
- Shallow depth to bedrock.

These soils comprise approximately 47% of the site.

A geotechnical engineering report may not be required for the Group B Soils if adequate provisions to circumvent soil-related problems are incorporated into the site plan, or if the location of these soils will not impact the proposed development. Onsite soils within this problem class are the Manassas and Readington soils. Some of the characteristics which are typical of these soils include:

- Low bearing values for foundation supports,
- High seasonal ground water tables in drainage ways or low-lying areas,
- Perched ground water above restrictive soil or rock layers, and
- Shallow depth to bedrock.

These soils comprise approximately 11% of the subject site.

A geotechnical engineering report is usually not required for the Group C Soils as long as construction is in natural soils and not in controlled fills. Onsite soils within this problem class are the Penn and Bucks soils. Some of the characteristics which are typical of these soils include:

- Shallow depth to bedrock, and
- Slow permeability rates.

These soils comprise approximately 42% of the subject site.

In conclusion, based upon the information reviewed, a geotechnical investigation and report will be required for the development of the subject site.

WETLANDS/OFFICE INVESTIGATION

An office investigation was conducted to determine the possible existence of wetlands on the subject site. The U.S. Fish & Wildlife Service National Wetland Inventory (NWI) mapping for this area (Herndon, Virginia—USGS Quad Sheet) was reviewed and it shows an area of Palustrine Forested Wetlands along Oxlick ranch northwest of the property. Please refer to Attachment #6, NWI Map. Additional areas of Palustrine Forested Wetlands and Palustrine Open Water Wetlands are shown on adjacent properties to the north and west of the subject site.

While the NWI Mapping is generally a reliable source for identifying the most obvious areas of wetlands, it is important to note that the mapping is compiled from aerial photography and omissions of existing wetlands typically occur. For this reason, it is essential that other sources of information be utilized to determine the possible existence of additional wetlands.

As an additional source of information, the Fairfax County Soils Survey was reviewed to determine if any of the onsite soils exhibit characteristics commonly associated with nontidal wetlands. The presence of these soils, commonly referred to as Hydric Soils, indicates a high probability of wetlands occurring within a particular area. In this regard, the Fairfax County Soils Scientist has assigned a Wetlands Probability Index to every soil type that occurs within the County. Hydric Soils, with the highest probability of supporting wetlands, were assigned an index of one (1). As the index increases to a maximum value of five (5), the likelihood of wetlands occurring decreases. The Wetland Probability Index associated with each of the onsite soils can be summarized as follows:

Soil Number	Soil Name	Wetlands Probability Index	Hydric	Percentage of Site
1	Mixed Alluvial	1	Yes	1% ±
14	Manassas	4	No	7% ±
67	Penn	5	No	41% ±
72	Bucks (L)	5	No	<1% ±
76	Calverton (L)	4	No	16% ±
80	Croton	1	Yes	30% ±
273	Readington	4	No	4% ±

Please refer to Attachment #7, Hydric Soils Map.

Based upon a countywide average, a Wetlands Probability Index of one (1) suggests that from 80% to 100% of the area containing Mixed Alluvial and Croton soils may contain wetlands. An index of four (4) suggests that from 5% to 20% of the area containing Manassas, Calverton and Readington soils may contain wetlands. An index of five (5) suggests that from 0% to 5% of the area containing the Penn and Bucks soils may contain wetlands. Based upon these probabilities, the total acreage of the subject site which may contain wetlands can be summarized as follows:

Soil Name	Acreage	Wetlands Probability	Possible Acreage of Wetlands
Mixed Alluvial and Croton	9.3±	80%–100%	7.4–9.3
Manassas, Calverton, and Readington	8.1±	5%–20%	0.4–1.6
Penn and Bucks	12.6±	0%–5%	0.0–0.6
TOTALS	30.0±		7.8–11.5

In conclusion, based upon the information reviewed, the presence of wetlands may have a significant effect on the development of the subject site. For this reason, a field investigation is recommended to better define the acreage which may fall under the jurisdiction of Section 404 of the Clean Water Act.

WETLANDS/FIELD INVESTIGATION

On January 10, 1992, a preliminary wetlands assessment was conducted on the subject site. Wetlands were identified following the procedures set forth in the *Corps of Engineers Wetlands Delineation Manual* (1987). The field investigation involved the collection of data documenting hydrologic conditions, soil characteristics and dominant vegetation in order to establish an approximate wetlands boundary.

Soil saturation and inundation was observed in three areas. Soil color indicative of hydric soil conditions was also present. Dominant vegetation common to all wetlands on the site include soft rush, woolgrass, redtop bentgrass, marsh fern and several sedges. Buttonbush, red maple and sweet gum were the dominant shrubs in the southern and northwestern wetlands areas. The total amount of jurisdictional areas delineated on the site was approximately 3.7 acres. Please refer to Attachment #6, National Wetlands Inventory Map.

FLOODPLAIN

The Federal Emergency Management Agency (FEMA) and United States Geological Survey (USGS) maps were reviewed for the possible existence of floodplains in the vicinity of the subject site. Both sources indicate that the closest floodplain is located offsite approximately 3,000 feet northwest of the subject site along Oxlick Branch. Please refer to Attachment #8, FEMA Map.

Oxlick Branch passes within approximately 80 feet of the northeast corner of the property. This is just downstream of the triple box culvert which carries the stream under the Fairfax County Parkway.

The drainage area contributing to Oxlick Branch at this point is greater than 70 acres and by Fairfax County definition will require the delineation of a floodplain. A review of Fairfax County Parkway storm computations and available topography indicate that the estimated 100-year flood elevation (approximately 4 feet above the stream bed) will not encroach on the subject site.

STORMWATER MANAGEMENT REQUIREMENTS

A ridge line bisects the site into two major drainage divides. The northern portion (± 18 acres) drains into Oxlick Branch, which is a tributary of Flatlick Branch. The southern portion (± 12 acres) drains such across Route 50, eventually entering Little Rocky Run. The runoff draining from the northern portion of the site exits at two low points; approximately 12 acres exit at the northwest corner of the site. There are approximately 14 acres, of which approximately eight areas are from offsite, exiting at the northeast corner.

The subject site is located in the Cub Run drainage shed. This shed flows into the Occoquan Reservoir which is the water supply source for a large portion of Fairfax County. Subsequently, development of this property is subject to the implementation of specially designed water quality control measures for stormwater runoff, referred to as Best Management Practices (BMPs). Depending on the proposed development program of the subject site, stormwater management and BMPs could be accommodated in the form of two or three detention ponds. One of these ponds could be located at the southern low point of the site near the culvert crossing Route 50. The other pond(s) could be located at one or both of the low points along the northern boundary of the site. Please refer to Attachment #9, Drainage Map

Preliminary calculations indicate that approximately 85,000 cubic feet of total storage volume may be necessary to satisfy detention and BMP requirements for the full development of the site. Fairfax County's "Policy and Requirements for Adequate Drainage" require that a developing site convey stormwater runoff into a natural watercourse or storm drainage pipe of sufficient capacity without causing adverse impacts on the watercourse or downstream properties. A preliminary field investigation indicated that the two outfalls to the north may be inadequate to accommodate concentrated stormwater runoff. The drainageway outfalling northwest of the site is of particular concern. As a result, offsite watercourse improvements and/or storm sewer facilities and associated offsite storm drainage easements may be necessary to remedy any inadequacies. A more detailed analysis of this situation will be required as development of the subject site progresses.

CHESAPEAKE BAY PRESERVATION ORDINANCE IMPACTS

A preliminary investigation was conducted to determine the potential impact of the Chesapeake Bay Preservation Ordinance on the development of the subject site. In this regard, the following Resource Protection Area (RPA) features were investigated:

- Tidal Wetlands and Tidal Shores—Since this area of the County is not subject to the influence of tides, these features are not applicable.
- Tributary Streams—As mentioned previously, none of the onsite swales are depicted as tributary or perennial streams on the USGS Quad Sheet; therefore, this feature is not applicable.
- Water Courses With Drainage Areas Greater Than 70 Acres—As mentioned previously, Oxlick Branch, located northeast of the subject site, drains an area greater than 70 acres; therefore, this stream is by definition a RPA feature.
- Nontidal Wetlands Connected By Surface Flow and Contigous to a Tidal Wetlands or Tributary Stream—As previously mentioned, there are no tidal wetlands or tributary streams within the immediate vicinity of this property; therefore, the nontidal wetlands as discussed in the section entitled "Wetlands/Field Investigation" are not considered RPA features because they are not contiguous to tidal wetlands or tributary streams.

Based upon this phase of the investigation, Oxlick Branch is the only RPA feature in the vicinity of the subject site.

The provisions of the ordinance require the establishment of a buffer area to protect other components of the RPA from significant degradation due to land disturbing activities. In this regard, the following components, which comprise a buffer area, were investigated:

- Any land within a floodplain—As mentioned previously, the estimated floodplain for Oxlick Branch does not impact the subject site; therefore, this component is not applicable.
- Any nontidal wetland that is continuously connected to a watercourse—None of the onsite wetlands are continuously connected to Oxlick Branch; therefore, this component is not applicable.
- Any land within 100 feet of a RPA feature—As mentioned previously, Oxlick Branch passes within 100 feet of the subject site, therefore, this 100 feet buffer encroaches upon the subject site.
- Any land with a slope greater than or equal to fifteen (15) percent where such slope begins within fifty (50) feet of a floodplain—As mentioned previously, a small area of slopes in excess of 15 percent are found on the subject site, however, these slopes are not within 50 feet of the Oxlick Branch flood plain; therefore, this component is not applicable.

Oxlick Branch, as a RPA feature, is combined with the 100-foot setback, which acts as a buffer area, to form the Resource Protection Area (RPA) as shown on Attachment #10, RPA Map. The remainder of the site is designated a Resource Management Area (RMA).

It should be noted that this investigation is based upon the Chesapeake Bay Preservation Ordinance as endorsed by the Fairfax County Board of Supervisors (BOS) on May 20, 1991. As a condition of approval, this ordinance is currently being reviewed by the Chesapeake Bay Local Assistance Board (CBLAB). A date for official adoption of the Ordinance by the BOS has not yet been established.

In the event that the Chesapeake Bay Preservation Ordinance has not been officially adopted at the time the subject site moves forward into the zoning process, the County will impose their Environmental Quality Corridor (EQC) policy as a condition of development. Since the components of an EQC are essentially the same as those for a RPA, the impacted area would remain unchanged.

QUALIFIER

This report is a *preliminary* engineering analysis of the subject site's development potential. Issues addressed were limited to:

- Tract Location
- Zoning/Comprehensive Plan
- Utility Availability (Water and Sanitary Sewer)
- Transportation/Access Requirements
- Site Characteristics/Topography
- Soils
- Wetlands (Office and Field Investigations)
- Floodplain
- Stormwater Management Requirements, and
- Chesapeake Bay Preservation Ordinance Impacts

This report is a *preliminary* engineering analysis of the subject site's development potential. Issues addressed were limited to: relate to subjects beyond the scope of this study.

Much of the information presented herein was obtained from public officials whose opinions are generally reliable and sufficient for preliminary planning purposes.

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PART II.B. SITE ANALYSIS: ALLOWABLE USE OF SITE

CHAPTER 6

REAL PROPERTY LAW

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UNDERSTANDING LAW TO GUIDE IN BOUNDARY DETERMINATION

Real property law is a combination of constitutional law, common law, and statutory law. Constitutional law is the supreme legal source in a jurisdiction, which takes precedence over common law or statutory law. Common law is that group of rules and standards of action originating from customs and usages (or "use") as determined in actual cases. The common law derives its authority from judgments and decrees of courts affirming those customs and usage. Statutory law is created by acts of legislative branches of government. Legislative branches of government exist at the national, state, and local level. The surveyor should note that within the broad categories of constitutional law, common law, and statutory law, there are many specialized areas of law concerning real property.

Real property law directly affects the practice of surveying. The surveyor works within the established legal system; therefore, the surveyor must have knowledge of real property law to be able to recognize potential legal problems that might arise as a result of the surveyor's findings. Knowledge of real property law also provides a foundation to the surveyor for making decisions to resolve potential problems.

A surveyor's clients are best served when a surveyor makes decisions based on the law because such decisions are less likely to be challenged than decisions with no legal foundation. To make decisions founded on law, the surveyor's knowledge of law must include not only real property law, but also the legal rules governing surveyors. Surveyors are governed by rules of state registration boards. State registration boards establish rules under the authority of enabling statutes. Anyone wishing copies of such rules should contact the appropriate state board.

To make decisions based on law, the surveyor may have to engage in legal research to find the relevant case law. Case law provides court decisions applying the law (whether constitutional law, common law, or statutory law) to a specific set of facts and circumstances. A surveyor must search for case law that applies the law to facts and circumstances similar to the situation confronting the surveyor. While a working knowledge of legal research techniques, constitutional law, common law, statutory law, and the related case law is helpful, the surveyor should be mindful of the fact that the rendering of legal opinions or hypotheses to others may constitute the unauthorized practice of law. The surveyor should never review sources of law and attempt to provide a client with what could be construed as a legal opinion or legal advice.

Sources of Law

In order to uncover applicable law, the surveyor should be cognizant of the sources of law. As indicated in the following subsections, there exists a multitiered system of law and sources of law in the United States.

Constitutional Law. The U.S. Constitution is the supreme law of the land. The Constitution, technically speaking, is the result of sovereign states granting certain enumerated and specified powers to a federal government, reserving the residue of their powers to themselves. The U.S. Constitution takes precedence over and controls any state or local laws that conflict with the Constitution's express or implied provisions. Therefore, the first and primary source of law is the U.S. Constitution and its 27 amendments.

The U.S. Constitution is applied primarily through court orders stemming from actual cases filed in the federal and state courts. The final arbiter and interpreter of the U.S. Constitution is the U.S. Supreme Court. While inferior federal and state courts have jurisdiction to interpret the Constitution, the Supreme Court's word is final and controlling. Interpretive questions concerning the Constitution may be found in the issued written opinions of courts that hear and decide constitutional questions. Following is a discussion of those courts that could issue opinions and orders concerning constitutional questions. These written opinions and orders may be located in the various Reporters (compiled casebooks) in any law library.

Written opinions of the U.S. Supreme Court from 1790 forward may be found in compiled volumes of the *United States Reports* (official reporter) and in the compiled volumes of the *Supreme Court Reports, Supreme Court—Lawyers Edition Reports,* or the *Supreme Court—United States Law Week Reports* (unofficial reporters).

Written opinions of the U.S. Courts of Appeals from 1789 forward may be found in the compiled volumes of the *Federal Reports* (official reporter) or in the *Federal Courts—United States Law Week Reports* (unofficial reporter). There are 12 sitting U.S. Courts of Appeals. The U.S. Courts of Appeals are appellate (nontrial) courts that hear appeals from the U.S. District (trial) courts. Appeals from the U.S. Courts of Appeals go directly to the Supreme Court. The primary federal courts to which persons bring cases and controversies concerning constitutional questions are the Federal District Courts, which conduct trials, collect evidence, in some instances, and issue written opinions. There exists at least one Federal District Court in each state or territory of the United States. Written opinions of the Federal District Courts may be found in the *Federal Supplement Reports* (official reporter).

Each of the 50 states has a sitting state supreme court that occasionally decides cases and issues concerning the U.S. Constitution. The decisions and opinions of these state supreme courts may be found in the various state reporters, such as *Florida Reports* and *Virginia Reports,* and in the regional reporters compiled by the West Publishing Company, such as *Northeastern Reports* and *Southeastern Reports.*

Federal Statutory Law. The U.S. Congress exercises a wide range of legislative powers as allowed under the Constitution. Bills adopted by Congress and signed into law by the president are compiled in the codified statutes of the United States Code (U.S.C.), and, once codified, are identified by a numerical cite, such as "42 U.S.C. § 1983." The many volumes making up the United States Code may be located in any law library. Once legislated into existence, United States Code statutes may be the subject of interpretation in the federal courts, as is the U.S. Constitution.

Federal Regulatory Law. The many departments and administrations of the U.S. government executive branch periodically issue regulations and orders concerning the application of federal statutory (United States Code) law. These regulations, while not rising to the level of legislative branch law created through the Congress-to-president process, are sources of binding law greatly affecting the lives of U.S. citizens. These regulations may be located within the codified *Federal Register* (Fed. Reg) and, once codified, are also identified by a numerical cite, such as "42 Fed. Reg. § 1983." Once promulgated, federal regulations may be the subject of interpretation in the federal courts, as are United States Code statutes.

State Statutory Law. All 50 states have enacted codified statutes containing laws passed by the respective state legislatures and signed by the respective state governors. These state-codified statutes possess names such as Code of Alabama, North Carolina General Statutes, or Virginia Code Annotated and may be located within any law library. These state codes are highly important sources of law, as most statutory and regulatory schemes concerning real property originate at the state, and not the federal, level. State enabling acts concerning the planning, zoning, and subdivision powers of localities may be found within these state-codified statute volumes. Individual statutes are identified by a numerical cite such as "Virginia Code Ann. § 15.1-475." Once legislated into existence, state statutes may be the subjects of interpretation in the state courts and occasionally in the federal courts. The individual state supreme courts have the final interpretive say on what the individual state codified statutes mean. For example, if the U.S. Supreme Court and the Iowa Supreme Court reach a difference of opinion on what an Iowa-codified statute really means, the opinion of the Iowa Supreme Court will control.

State Common or Case Law. As previously mentioned, state supreme courts issue written opinions and orders concerning the interpretation or application of state statutory law and report their decisions in the various state reporters and in West's regional reporters. Almost all of these reported decisions stem from appellate cases originally heard by state trial courts. In understanding how a certain state-codified statute is applied or interpreted, one needs to read the reported decisions wherein the statute was reviewed and analyzed by a state supreme court in an actual appellate case situation. To assist in this effort, most of the state-codified statutes contain case annotations after each individual statute listing those reported decisions wherein the statute was reviewed and applied.

Local Charters and Ordinances. Individual counties, cities, and towns have the power to adopt local codified ordinances within the scope of authority granted by their respective state governments. Zoning ordinances, subdivision ordinances, and site plan regulations are almost always found within these local ordinances. These ordinances are adopted by the respective local governing bodies, namely, county boards, city councils, or town councils. As such, surveyors should own a copy of the local ordinances for each jurisdiction in which they work. Most of the legal research into codified law conducted by surveyors deals with local ordinances, as opposed to federal- or state-codified law. In addition to their own local ordinances, incorporated municipalities (cities and towns) have individual charters adopted by the state governments. These charters are usually found within the local codified ordinances or in a separate volume and contain specific grants of authority or powers to the municipality as determined by the state government.

Introduction to Property Law

Law forms the basis on which land ownership exists. Proof of the limits of this ownership requires gathering evidence by surveying the boundary. Surveyors should remember that each law has many exceptions. Each land survey is unique and different. This is because the physical characteristics of the land vary, and the circumstances surrounding the conveyance govern the interpretation of the intentions of the parties.

In addition to this basic knowledge of law, surveyors must be familiar with state statutes and local ordinances. They must have knowledge of case law that refers to boundaries. When a conflict over a boundary develops, surveyors should investigate any related surveys and cases that might exist.

The practice of land surveying requires some understanding of laws related to property ownership, which should include laws related to boundaries, adverse possession, and easements. This basic introduction to law is necessary for understanding the case law related to specific situations. The references to sources of law previously provided should be helpful in this regard.

Property law in the United States derives authority from many sources. The Constitution of the United States, laws passed by Congress, and the laws passed by state legislatures are the bases of statutory laws concerning property ownership. Federal boards and commissions pass regulations that affect and control property rights. State constitutions and property laws passed by state legislatures also contribute to the vast number of laws dealing with property ownership rights. Other sources of law include state and municipal regulations, as well as local ordinances. Perhaps most important to surveyors are court decisions and rulings related to land and its ownership. In reading statutory law together with relevant court-made (common or case) law, one may understand the totality of the law applicable to a given situation.

Classification of Property

Property, in the legal sense, is that which belongs exclusively to someone. It is an aggregate of guaranteed and protected rights. Those rights, covered by the word *property,* fall into various subdivisions. Absolute property, common property, personal property, community property, private property, public property, and real property are but some of the categories. The specific category depends in part on who owns the property, the degree of ownership, and the qualities or characteristics of the property or property right.

The surveyor or engineer involved in a land development project must be familiar with real property because this category involves the rights of ownership of land and anything erected on, growing on, or affixed to the land. Real property involves the rights associated with the land. (See Figure 6.1.)

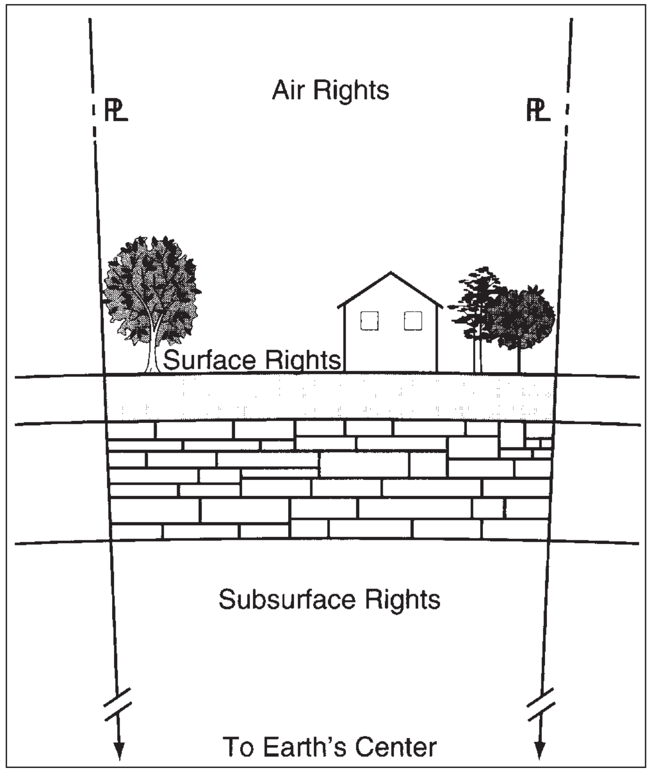

FIGURE 6.1 Real property rights extend above and beneath.

The word *land* in law usually means tenements and hereditaments. A *tenement,* in the proper context, is everything of a permanent nature that one holds exclusively as his or hers. *Hereditaments* are everything inheritable including both real and personal properties. Hereditaments are much broader in scope than tenements. Land includes the soil and everything attached to the soil. The attachment can be natural, as with a tree, or attached by man, as with a building. In theory, this ownership extends outward to the heavens and inward to an apex, or point, at the center of the earth.

These definitions are the first step in the classification of property. Ownership is a collection of rights that one has assembled and can use for the enjoyment of property. This includes the right to transfer these rights to others. (See Figure 6.2.) This collection of rights can and often is a complex one. It is this complexity that generates the need for further classifying rights or property. Property ownership may be described as the possession of a bundle of rights. Therefore, an inquiry into title will include an analysis of which rights a property owner possesses.

Real property and estate in lands include "lands, tenements or hereditaments" (Black, 1990). A tenement "signifies everything that may be *holden,* provided it be of a permanent nature" (Black, 1990). For example, a building on a parcel of land would be considered a tenement, as well as the land itself. Hereditaments mean things capable of being inherited, whether corporeal or incorporeal. Therefore, hereditaments would include tenements and land because tenements and land may be inherited. Corporeal hereditaments are simply "substantial permanent objects

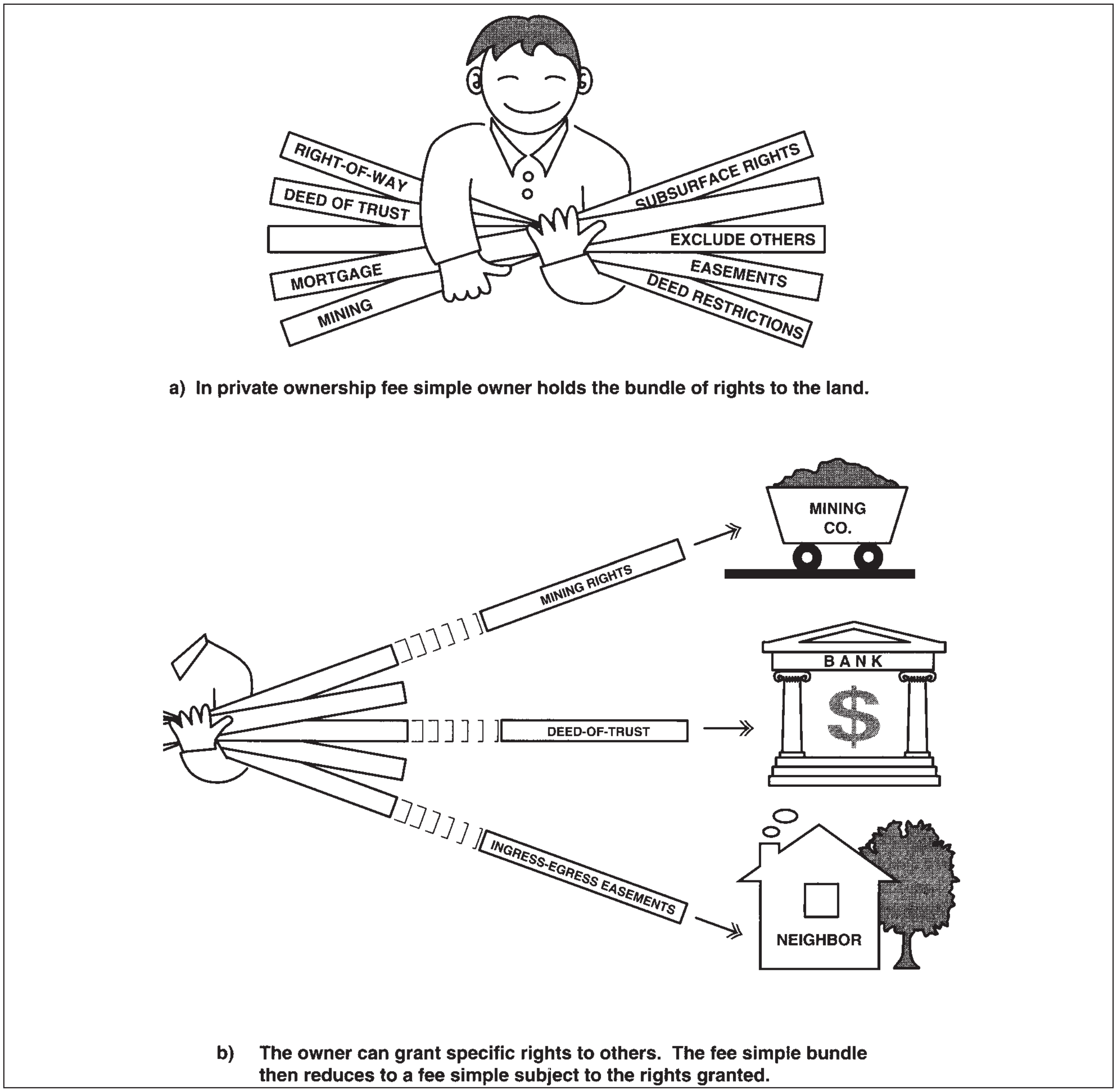

FIGURE 6.2 Property ownership is a bundle of rights that can be conveyed in whole or in part.

which may be inherited" (Black, 1990). Incorporeal hereditaments are "anything, the subject of property, which is inheritable and not tangible or visible" (Black, 1990). For example, the rents from a parcel of land are an incorporeal hereditament.

The degree of ownership that exists completes the classification. The legal term for this degree of ownership is the *type of estate*. This is the interest held in land or other subject property and is possessory or may become possessory. Since this interest can vary in degree, the estates vary in type.

TYPES OF ESTATES AND THE HISTORY OF THEIR ORIGIN

William the Conqueror's conquest of England resulted in all the lands of England being held by the king as sovereign ruler of the realm. No property law existed. The land and everything on it was the king's. Only the king could grant what was his.

In exchange for a pledge of personal loyalty, which included the obligation to fight in defense of the king's realm, the king would grant to each of his men (the lords and barons in his service) the use, possession, and profits of a portion of the king's land. Personal relationships, loyalty, and obligation, not law, governed.

Initially, the king was the sole dispenser of justice among his men, then the king in his court. Likewise, the king was the sole legislator, and later the king in parliament. The only limitations on the king's sovereignty were those the king placed on himself, whether voluntarily or involuntarily. Law is a limitation on a king's sovereignty in the sense that the king has chosen to accede to certain external rules.

However, long before property law existed, the king, to ensure loyalty, would exercise care in his treatment of his men. How the king treated one man created expectations among his other men. Land was no exception.

In time, the personal relationships between the king and his men and between his men and their men grew into a complex web of customs and practices. The result was the creation of a vast structure of land tenure, with laws governing personal obligations, interests, and rights concerning land.

The English land tenure[1] system was the "system of holding lands or tenements in subordination to some superior" (Black, 1990). For example, a knight may have held an estate in land in return for services to the king. Those who held an estate in land, such as knights, sometimes granted an estate in their land to others, who also granted to other persons subordinate to them. This gave rise to middle lords. The tenant in possession of the land was subordinate to all other estate holders.

The tenure system distinguished between free men and those not free. If the man was free, he received a free tenure; otherwise, the tenure was nonfree.

Free tenures included spiritual and lay tenures. An example of a spiritual tenure is *frankalmoigne,* which roughly translates as "free alms." Frankalmoigne is a tenure that permits a person to grant lands to religious orders or ecclesiastical bodies as a charitable act for the benefit of the grantor's soul and usually in return for prayers on behalf of the grantor and his family.

Lay tenures included tenures granted for chivalry or knight service, sergeanty, and free socage. Chivalry and knight service were held in higher esteem than the other forms of lay tenure. Tenure by sergeanty included services such as the keeping of the accounts for the land, and so on. Free socage tenure included services such as husbandry and baser services. Other types of free tenure also existed at different times in English history.

When this tenure system existed, a person attached to a manor to perform work on that manor was a class of serf known as a *villein.* These tenants were slaves. This situation led to a tenure in villeinage or an unfree tenure.

Originally, the common law courts did not protect unfree tenure. Eventually the courts protected the interest of the tenant. The rights and obligations of tenants became a matter of official record; thus, the tenure was copyhold tenure (Cheshire, 1949, pp. 22–26). These copyhold tenures were estates at the will of the lord. The titles to these estates consisted of court rolls prepared by the steward of the manor.

[1]Tenure is the direct result of feudalism, which separated the *dominium directum* (the dominion of the soil), which is placed mediately or immediately in the crown, from the *dominion utile* (the possessory title), the right to use and profits in the soil, designated by the term *seisin,* which is the highest interest a subject can acquire (*Black's Law Dictionary,* 1990).

Modern Classification

The property law system in the United States developed out of the English system, with the notable exception of the state of Louisiana, which developed out of the French (Napoleonic Code) system. The United States's property law system is composed of various estates, which can be broadly classified as estates of freehold and estates of less than freehold. Estates of freehold can be divided into two categories: estates of inheritance and estates not of inheritance, specifically, life estates. A life estate is an estate created for the duration of the life of some person.

Fee Simple Estates

Subdivision of fee estates depends on the interest held in the estate. Fee simple absolute is the most complete unencumbered estate known in law. The legal definition of the word *simple* is that there are no restrictions on the inheritance characteristics of such an estate. The use of *absolute* in this context means that the estate is not dependent on any happening or event. Transfer of these estates traditionally uses the phrase "to John Doe and his heirs." Court rulings state that the use of the word *heirs* is necessary to create an estate of inheritance in land.

Fee simple determinable estates, by comparison, automatically terminate upon a happening of an event. An example of this type of estate is a deed with a clause that would cause the estate to revert to the original owner or his or her heirs. A statement limiting use of the estate, such as "to be used only as a school" would cause a termination of that estate if the property ceased to be used as a school.

Other fee estates exist, such as a fee simple subject to some later condition and a fee simple subject to an executory limitation. The first of these is similar to fee simple determinable in that it confers the power on a successor in title to terminate an estate. This termination would take place based on a stated event but only if the successor exercises his or her power. Fee simple conditional and fee tail estates were contingent on or applying to heirs. In most states, these estates have been eliminated by statutes.

Estates Not of Inheritance

Allowing for limited use of estates while at the same time prohibiting inheritance by the user comes about through estates not of inheritance. These estates can be for one's own life. Estates granted to one for the life of another also exist. The legal term for this type of estate is *per autre vie.* Such estates created by acts of the parties are known as conventional life estates. Estates not of inheritance may come about by operation of the law. Operation of the law means that the law provides for estates for one's own life and for the life of another.

Instruments such as deeds, wills, and reservations are methods used to create conventional life estates. Creation of marital life estates comes about by operation of the law. Record checks for nonpossessory interests such as easements and licenses are always important. Easements that provide access for various services in land development projects make use of such interest.

Other types of estates are estates for years, estates from period to period, estates at will, and estates at sufferance. These estates are time dependent and usually of little consequence to the surveyor involved in land development.

Concurrent Ownership

Usually individuals hold estates in their own right (severally) without any other party joined with them in the estate. Estates held by a plurality of tenants with a common interest do, however, exist. Such ownerships are joint tenancies, tenancies in common, and tenancies by the entirety.

A conveyance to two or more persons usually creates a joint tenancy unless the terms of the instrument indicate otherwise. Each joint owner possesses an undivided interest in the whole property. No joint tenant owns any fractional interest.

Tenancy in common provides that each of the common tenants holds a separate and undivided interest in the land. The possession is, however, in unity with the other joint tenants with equal right of possession under distinct title. The difference between the two is that with a joint tenancy a right of survivorship exists, whereas with a tenancy in common it does not. Like joint tenants, tenants in common have an equal and undivided right to possession, but unlike joint tenants, tenants in common hold separate and distinct shares in the property.

An estate by the entirety is a form of coownership. A clear example of such an estate is that held by a husband and wife where each party has the right of survivorship. Such estates result when a husband and wife obtain land jointly after their marriage. Tenancy by the entirety differs from a joint tenancy in that tenants in entirety have no individual interests that they can convey; both must be involved if a conveyance is to take place.

Wills and Descent

In a general sense, a person's will is that person's wish or desire. By law, a person may express the person's will concerning the distribution of the person's estate at death through a signed writing called a *will*. The person making the will is typically called the *testator*.

All heirs have equal standing when they receive land by a will unless the will contains a specific statement to the contrary. This means that those heirs take their parts as assigned in the will proportional to the actual whole part. A simple example of this is where two sons were each willed 50 acres of land from a tract erroneously thought to be 100 acres. The actual area reported from a survey is 104 acres; therefore, each son would receive 52 acres.

Descent is the "succession to the ownership of an estate by inheritance, or by any act of law" (Black, 1990, s.v. "descent"). Descent can be lineal or collateral. Lineal is a descent from a grandfather or a father to a son or grandson. Collateral descent connects persons not directly related to each other as between brothers or cousins. Descent is the controlling factor when a person dies intestate (without having made a will). The laws of the state of residency regarding descent dictate the division of the deceased estate.

OWNERSHIP AND TRANSFER OF TITLE OF REAL PROPERTY

Deeds

A deed is a written instrument used to transfer an interest in land or real property. A deed is a form of contract, and, as such, a legally valid deed must meet certain requirements. A deed must have at least two parties: a grantor and a grantee. The grantor must own the interest and rights being conveyed. The interest and rights being conveyed must be described with reasonable specificity. The laws of the jurisdiction in which the land or real property is located must permit the transfer of the interest or rights described. The interest or rights being described must be current at the time of conveyance.

Unlike some contracts, which may be oral or written, a deed must be a written instrument. Because a deed is in writing, the possibility of fraud or perjury is reduced. This is the underlying rationale of England's Statute of Frauds of 1677, which required that a contract for the sale of land be in writing. The writing must be in legal words that clearly express the intent of the parties. These words must identify both grantor and grantee. The written words must convey the intent of the parties. The deed must include a descriptive clause and statement of the consideration involved. This is the *premises*. The deed must also contain a description, called the *habendum* clause, which defines the limits of the estate. This clause must agree with the premises. Words used to close the deed are the *tenendum*.

Deeds must state exceptions and reservations when such exist. The exceptions exclude parts of the estate described from the conveyance. These exceptions must not be greater than the whole estate. The reservations retain rights to the grantor of an estate.

The benefit of consideration to the grantor must exist as stated in the instrument of transfer. Consideration must pass between parties, and that consideration must be adequate compensation. The courts have ruled that a deed is valid only when the grant causes an exchange between parties. The reason for this requirement is to prevent fraud and misrepresentation. It also ensures that one party will not gain unfair advantage over the other party.

Laws require that parties to the deed have the opportunity to read and examine the document before its execution. Finally, the deed transfer consists of the signing of the instrument by the parties to the agreement. This step takes place before a notary or other person authorized to witness signatures. There is a requirement of delivery, or the actual placement of the instrument into the hands of the grantee. Strict interpretation of this requirement is rare.

Deeds used in the transfer of ownership in the United States are warranty deeds, quitclaim deeds, and deeds of bargain and sale. The warranty deed contains a covenant of title. This covenant is a guarantee by the grantor that the deed conveys a marketable title. Quitclaim deeds convey only the present interest of the grantor and do not warrant or guarantee good title. Deeds of bargain and sale convey definitive estates in land, but do not imply a warranty.

Land Descriptions

The description is a vital element in the deed or other title document. It must be clear in meaning and distinct in location, and the location must be unique to only one property. Two descriptions in a deed define the extent of one's land ownership. The form of the description can vary. Graphics and written words provide two basic methods for identifying land parcels. The metes-and-bounds or written form is common. This is a combination of measured values (metes) with the bounds (boundary of the land), which when used together define the extent of land ownership. In these descriptions metes comprise the direction and length of travel. Monuments and calls of adjoining landowners fix the bounds.

Metes-and-bounds descriptions must begin at some known and easily identified point. The surveyor must establish this beginning point in a manner that facilitates its relocation with certainty if destroyed or removed. An additional requirement is that the courses and distances in a legal description proceed from corner to corner and return to the beginning point.

Reference to prior deeds or maps is an important part of the procedure of writing land descriptions. Land description by reference to maps and deeds is a common method used to describe property that is subject to transfer. Strip descriptions and area descriptions are other, less-used forms for defining land ownership. Proportional conveyances that call for parts of larger tracts often describe land in states that use the public land survey system. Combinations of various types of descriptions appear in the transfer of ownership of a parcel of land.

The being clause, the body, the qualifying clause, and the augmenting clause constitute the total description. "The being clause of a deed denotes the origin of the history of the present deed" (Brown, Landgraf, and Uzes, 1969, p. 347). The body is the actual description. Qualifying clauses are those statements used for exceptions and restrictions among others in the deed. Descriptions incorporate augmenting clauses for easements and other items when necessary.

Any form of description must meet the requirements of the law for a conveyance to be complete. Deeds must be in writing and must include the grantor (vendor) and grantee (vendee). The description must clearly identify the interest conveyed. There must be an expressed intent to convey the property identified by the description.

Some items can invalidate legal descriptions, but courts have been hesitant to declare legal descriptions ineffectual because of uncertainties. Supportive information often helps to clarify descriptions. Such information is available from the official records, the assessor's office, old maps, and extrinsic evidence.

Adverse Possession

Ownership under the doctrine of adverse possession is a result of statutes of limitations related to recovery of real property interests. The modern principle of specifying a uniform number of years as the limitation period for real property actions began during the reign of Henry VIII. Early American colonies followed a limitation period of 20 years as it was set in the 1623 Statute of James I. Several states today have continued that practice. Under the early statute, a dispossessed freeholder had the chance to regain possession and claim to the estate of freehold (seisin).

Property claimants today may recover an interest in real property by bringing an action similar to the ancient writ previously described. The dispossessed party must seek a writ of right or possession before the statute of limitations expires. If the statute of limitations expires before the dispossessed party acts, the adverse possessor's rights in the property become absolute. The modern principle of adverse possession differs because the record owner does not lose title or ownership when the adverse possession begins. He or she can lose title only after the statute of limitations has run.

On first thought, this concept appears rather harsh, but on closer examination, the principle is necessary. There are many reasons to support the doctrine of adverse possession. Among those often advanced is the curing of conveyancing defects that have gone undetected in the possessor's chain of title. Limiting the length of a reasonable title search is a justification used by some. Enhancing the ability to transfer the land and make productive utilization of property are additional reasons for the statute. Another reason for the doctrine of adverse possession is to prevent a record owner from claiming improvements made by the adverse possessor in reliance on the record owner's lack of challenge to the adverse possessor's activities. Finally, giving certainty to long-standing boundaries supports the statute of adverse possession.

When the claimant proves that the requirements for adverse possession have been met, the record title owner loses that title. The person satisfying the requirements of adverse possession becomes the new owner of the property with a new and perfect title. Gaining of title by adverse possession is dependent on many factors. It does not, however, depend on a deed or patent. The possession must be open and notorious, continuous, hostile, actual, visible, distinct and exclusive, and under a claim of title or right. To satisfy the required statute of limitations, the statutory period to defeat title is necessary (Brown, Landgraf, and Uzes, 1969, sec. 2.34). Statutes of limitation generally state that after the requirements are fulfilled by the adverse possessor, the record owner is barred from bringing an action for recovery.

It is imperative that elements inherent to this type of possession exist before the courts will uphold claims under this doctrine. Record owners must have actual knowledge of the adverse claims against their holdings. Such terms as open, notorious, actual, and visible raise the presumption at law of notice. Intentionally infringing on the rights of the true owner with notice is necessary to meet one of the requirements.

Exclusive possession is also an essential ingredient for adverse possession. One manner of showing is if the adverse claimant denies right of entry to or use of the property by anyone without his or her permission. The claimant must deprive the rightful owner of his or her possession. Land used in common with others is obviously not exclusive possession, but if that use is only by permission of the adverse claimant, it is still exclusive use.

Legal rights are not the only basis for hostility. Hostility exists when an adverse claimant occupies property as his or her own with full intentions to hold it regardless of any other person's rights or title. Hostile possession is a term often misunderstood. Case law provides example and clarification of the term. The majority rule is that possession based on a survey mistake is sufficiently hostile. This is true as long as the person in possession is claiming the property as his or her own (Powell and Rohan, 1987, ¶ 1013[2][f][i]).

The requirement of continuous possession is necessary so that the true record owner of the land has had suitable cause while the time of possession runs its course. This allows the true record owner to bring legal action to evict the adverse claimant. Any break in the possession by an adverse claimant before the statutes of limitation expires, no matter how short the break in possession, reestablishes possession to the title owner.

Good faith requires that the person making an adverse possession claim truly believes that he or she has obtained a good title. He or she further believes that the taking of the title was proper. This requirement is not always necessary but is contingent upon the type of possession.

Ownership may be established in a variety of ways, including through adverse possession, each of which carries its own requirements. A surveyor must be careful not to mix title issues with location, or boundary, issues. Surveying involves the location of a parcel of land, whereas a right to or ownership of the land is a matter of law, often ultimately for the court to decide. Surveyors may locate any parcel of land, define it, and map it, so long as they do not render an opinion of title. In surveying a parcel based on a land description, such as from a deed, the surveyor should note differences between what the deed encompasses and what is actually occupied, or possessed. Differences may be attributable to a number of unwritten doctrines, adverse possession among them, or even additional deeds. The difference then, between record title and possession, may be dealt with through the legal system. A quiet title action is one method of accomplishing this. When adverse possession is a possibility, the surveyor's responsibility is to show the evidence thereof in relation to the boundary lines as described in the records. The final determination of a successful claim of adverse possession lies with the courts, not with the surveyor.

Easements

The general definition of an *easement* is a right granted by the owner of a parcel of land. This right, granted to another party, is for use of the land for a specified purpose. Easements are critical to land development, and this section will include more details concerning them. Various types of easements exist for various purposes.

The manner and reason for creating an easement determines its type and category. There are many common examples of easements, and nine prevalent means exist to create them: grant, dedication, condemnation (eminent domain), statutory layout, prescription, implication, necessity (a type of implied easement), express reservation, and estoppel. The foregoing list is provided to apprise those persons involved in land development of the many types of easements that may exist. The surveyor or engineer must uncover existing easements before the commencement of design work on the development project. Knowledge of the various means of creating them should assist in this task.

Easements appurtenant and easements in gross form two broad categories that include the various types. An easement created for use with specific land, the dominant estate, is an easement appurtenant. Such an easement consists of privileges of a person to use the land of another, the servient estate. This use must be in a particular manner and for a particular purpose. Such an easement can restrict the rights of the servient owner and may prevent him from using his own land for certain activities. Failure to restrict an easement to a dominant estate creates an easement in gross. Easements in gross are personal interests or rights to use land belonging to another. These uses are independent of ownership of any specific property.

Creation of easements by express agreement generally arises from a deed of grant; however, occasionally one is created by verbal agreement. This is true regardless of the duration of the interest conveyed.

Dedication of an easement consists of the appropriation of land to the public use. The rightful owner must make the dedications and an acceptance must follow for the right to become public. Easement by condemnation is the process whereby property of a private owner is taken for use by the public. When this occurs without consent of the private owner, that owner receives an award of compensation for his or her loss.

Acquisitions of easements by statutory layout proceedings provide for ingress and egress to public highways over intervening land. These easements provide for this access when no other reasonable way is available for cultivation, timbering, mining, manufacturing plants, or public or private cemeteries. State statutes vary, as do the methods for establishing these ways.

Easements acquired by long and continual use by an individual are easements of prescription. The required period of use is usually the same as that for accomplishing adverse possession. This period is a prescriptive period and varies among states.

An easement of necessity arises when parties grant land but fail to provide access to a highway except over the land remaining with the grantor. In such instances, an easement by necessity or by implication provides for access over the seller's remaining land.

Quite often, public and private cemeteries obtain access through easements either by necessity or through dedication. As a matter of sound practice, however, express deeded easements should be provided when cemeteries are created.

Implied easements evolve through implication, prior use, necessity, or prior map or plat dedication. The crucial element for an implied easement is that of prior uses. Often nondocumentary, these easements must be recognizable through a reasonable inspection of the property. A property survey should therefore reveal easements of the implied type. The requirement of appearance and visibility of such easements extends beyond professional scrutiny and includes the grantee of property. They constitute necessary and reasonable use of the property subjected to these easements. Such easements can affect land development.

Here is an example of an implied easement: Party A owns two lots. Lot one contains the home of party A. A sewer line runs from this home across the second lot owned by party A. There is a catch basin located on the second lot. Party A sells the second lot to party B. The visible catch basin is sufficient evidence and notice to party B that an easement for drainage, over the lot mentioned, exists.

Creation of easements by reservation and exception allows an owner who conveys a possessory interest to a party or parties to except or exclude a corporeal interest from the terms of his grant.

Estoppel forms the basis of creation of some easements. These easements can restrict the grantor in the use of his or her land. The following example from the case of *Battle Creek v. Goguac Resort Association*[2] illustrates such a situation. In this instance, the Goguac Resort was a riparian owner on a lake. The resort sold land for an easement to Battle Creek knowing that the city wanted water from the lake for municipal purposes. The resort company was later estopped from use of the lake because the resort use contaminated the lake, making the water unfit for the city.

Both affirmative and negative easements are common in occurrence. Affirmative easements are those that allow activity on the estate burdened by the easement. Some activities mentioned in easements restrict burdened estates. When such is the case, negative easements result.

Examples of affirmative easements include alleys, the approach to airports, private roads through subdivisions, and railway rights. Other easements include pipelines, utility poles, and electrical transmission lines. Party wall agreements and public utility dedications are also easements. When appropriate, use easements to cover the use of springs and wells. Important too, are surface rights to serve oil and gas leases. Easements provide a way to grant rights to flood land or drain land. Other uses for easements are to allow for encroachments and to provide for excavation along boundaries. They also exist to carry out temporary building construction beyond the limits of the project. Some of these easements are nonaccess easements, but most include rights of entry for reasonable maintenance.

If a current title search, commitment, or policy is not provided, the surveyor may search the public records to find documentation of express easements. An express easement would constitute a separate grantor-to-grantee conveyance in the title search. If the surveyor does not undertake such a search, the client should be so notified.

Negative easements are those that prevent specific activities by the servient estate owner. These usually prevent certain types of improvements to protect the easement owner's rights. Such rights might include scenic views and access to sunlight.

Locations of future easements, which are required because of the development project, should receive consideration while the boundary survey is in progress. To identify potential future easements, the surveyor should reference service lines of different types that adjoin or cross the subject property. The owner of property burdened with an easement and the benefited dominant interest (the *easement owner*) can seek remedies. Typical of remedies available to aggrieved burdened property owners are self-help, award of damages, injunctive relief, declaratory judgment, quiet title judgment, and replevin. Actions available to aggrieved easement owners include all the above with one exception, which is replevin.

The definition of *self-help* is an action that falls short of judicial action. Such action cannot result in a breach of the peace. A good example of self-help developed when an easement owner removed a garden from an area covered under some type of easement. The garden, planted by the burdened landowner, interfered with rights of the easement owner. The action of the aggrieved easement owner in no way breached the peace.

Damages result from unreasonable interference with easement use or unwarranted use of easements. Granting an easement usually makes the easement owner responsible for the maintenance and care of the area covered by that easement. Such an example existed when a young boy entered onto property burdened by an easement for a power line and climbed a tree growing within the easement. In climbing the tree, the boy touched the power lines and sustained injury. In this case, the court upheld damages sought against the easement owner. The court reasoned that the power company was the rightful easement owner and therefore unable to shift liability to the burdened property owner.[3]

[2]181 Mich. 241 (1914).

[3]*Gnau v. Union Electric Company*, 672 S.W.2d 142 (Mo.Ct.App. 1984).

The most common relief available to easement owners or burdened property owners is *injunctive relief.* Through this type of relief the easement owner would seek the enforcement of the rights of the easements. A burdened landowner would likely seek such an injunction to stay the use of the easement. Remedy by injunctive action will not preclude awards of damages.

Declaratory judgments, in particular, provide clarity when defining the limits of easements and their location. One may seek the assistance of the court in the determination of the extent and dimensions of easements not clearly defined. This is accomplished through an action for quiet title. Such matters can become crucial. Easements left undefined when producing a boundary survey often subject land development projects to unwanted problems.

A purchaser can bring legal proceedings to clear a purported easement through a *quiet title* action. For the buyer to take action, he or she needs neither to give notice nor to wait for the owner of the easement to respond to a complaint. The purchaser can take the initiative for removing a purported easement from his or her property. This is the most effective means of clearing property from encumbrances to convey title without objection. A quiet title action can also serve an easement owner in the establishment and determination of extent of an easement.

In one illustrative case, *Castanza v. Wagner,*[4] the burdened property owners sought quiet title and an injunction. They were successful in restricting the easement across their property to the width of the easement (between 12 and 16 feet). A recorded real estate contract made at the time their predecessors obtained the burdened property contained the reservation. A few weeks following the initial real estate contract's execution, the same grantor entered into a contract to convey the parcel benefiting from the reserved easement. The contract purported to transfer a 60-foot-wide easement across the neighboring, burdened land. The owners of the 60-foot easement attempted to widen a roadway within their claim, but the court did not allow the widening.

Replevin is an action available to a burdened landowner. This action enables the landowner to maintain control over his or her possessory rights. This control prevails in the face of the nonpossessory rights of the easement owner. One example of particular interest to those engaged in land development and concerning replevin involves public dedication of subdivision streets.

In this example, the landowner of a development dedicated the streets in a subdivision. The City of Lawton, Oklahoma then annexed them. The owner of the subdivision asked for reimbursement for water and sewer mains constructed by him. These lines lay within the dedicated limits of the streets. The city maintained that these installations were part of the dedication. The Oklahoma Supreme Court held that a landowner does not usually convey fee title and possessory rights when making a street dedication. The court allowed the developer to recover the value of the improvements under the street. This recovery of the value of improvements came about in an action of replevin.[5]

The term *profit à prendre* is defined as a nonpossessory interest in land with the right to take soil or substance from that land. This right to take something distinguishes profit à prendre from easements that only confer a right of use. Use of this profit often determines easement type. When profit derived from the easement is of benefit only to the dominant estate, then the easement is appurtenant. Use of the profit in ways other than to benefit the dominant estate creates a profit in gross. Since *appurtenant* means "belonging to the easement," it is also an accessory to the subject tract. Because of its relationship with the dominant tract, an easement appurtenant will pass to a grantee even if the transfer deed fails to mention it.

Title Report

Identifying and addressing issues affecting title to real property is a critical element in the transfer of ownership during the land development process. A title examination by an attorney will track the chain of title to real property over a specified period of time, and may uncover conveyances of a portion of the property either in fee simple or in rights of use, such as easements. Typically, however, the potential purchaser or the entity lending the money to purchase property will require that a title report be prepared by a company from whom a commitment for title insurance is to be issued. The owner of property not being sold, but intended to be developed, may also wish to obtain a title report to uncover potential pitfalls that may affect plans for development.

Title insurance that protects the investment of the lender is the most common form, although insurance to protect the interests of the buyer is also available at an additional cost. From the perspective of the lender, only insurance that protects his investment is required in most circumstances.

The title report is intended to reveal any information that might have an effect on the ability of the purchaser or owner to use the property. It will include a description of the property, any conveyances of ownership or use, liens or judgments against the property, and any special exceptions that might affect how the property can be used.

Special exceptions are shown in a separate category from the other items listed; typically the category is called Schedule B, Section 2. The items listed in this section are typically referenced as *survey exceptions,* and are reviewed by a surveyor when asked to provide a survey of the property. The surveyor will determine which of the special exceptions he or she is able to comment on and what effect (if any) they have on the use of the property.

When the surveyor is able to determine that certain special exceptions listed do not affect the property at all, the title insurance company will more than likely remove those items as exceptions to title for the purpose of issuing a commit-

[4] 43 Wash. App. 770, 719 P.2d 949 (1986).

[5] *Selected Investments Corporation v. City of Lawton,* 304 P.2d 967 (Okla. 1956).

ment for title insurance. Of the special exceptions determined by the surveyor to affect the use of the property, those that are capable of being graphically depicted on the survey drawing will be shown. Special exceptions that affect the property but are of a general nature, or those whose location is inadequately defined, will be noted by the surveyor, but their location cannot be depicted on the survey drawing.

The title report is an important element in the feasibility analysis conducted to determine whether a property is suitable for the user's intended purpose. A survey of the property will support the title report by identifying whether its boundaries actually match the description noted, and by addressing whether or not special exceptions listed affect the property. The standards usually required for the performance of the survey are those established by the American Land Title Association (ALTA) and the American Congress on Surveying and Mapping (ACSM). ALTA/ACSM Land Title Survey requirements will be discussed later in this chapter.

Eminent Domain

This is a right of the state that affects the rights of the private property owner. Eminent domain is the power held by governments and certain quasi-public entities to take private property for public use. Appropriation of private land for road construction, drainage channels, and laying water lines is common. This provides another way of obtaining access across private land. Normally, this power is reserved to governments. Many states, however, have adopted legislation extending this power to private individuals and other legal entities. In these instances, the power allows private owners to gain access to inaccessible (or landlocked) land.

Eminent domain differs from easement by necessity. The former requires compensation from the party claiming the power. Just compensation for land interests condemned is required by the U.S. Constitution and by some state constitutions. Easement by necessity requires no additional compensation other than the amount paid in the conveyance of the property involved. Land developers might use this power to gain rights-of-way in some situations, but the method is one of last resort because of the cost involved.

Dedication

Dedication is the voluntary granting of land interests by the rightful owner for public use. This topic is important because it is dedication that provides the means of transferring land from private ownership to public use. Land development projects include various public services within planned areas. Dedications to city or county governments provide for their long-term maintenance. Only the fee owner or his authorized agent can make these dedications.

Common law and statutory law provide for dedications. Common-law dedication confers only an easement. This dedication is not a transfer of rights. Such dedications do prevent burdened landowners from exercising their rights in a manner inconsistent with the rights of the public. This form of dedication is not a grant of land because there is no grantee. Common-law dedications transfer the land by estoppel in pais. *Estoppel in pais* is an estoppel by conduct of the parties compared to estoppel by deed, which rests on public records.

Statutory dedications occur when there is a grant of rights. These differ from common-law dedications because they pass legal title covering the area so dedicated to a governmental body or agency. Statutory dedication must comply with statutory law. Laws concerning dedication vary from state to state. To constitute a dedication either expressed or implied, there must be an intention, on the owner's part, to grant the property to some public use. A dedication is a voluntary action on the part of the fee owner. The party alleging a dedication must prove the intentions of the other party to do so (Skelton, 1930, p. 435). Open and visible conduct by the parties allows courts to determine their intentions to dedicate land for a particular use.

Plats show actual intention to reserve any portion of lands for the public good. If such a reservation is not on the plat, then an equally certain method is essential for establishing the intention to reserve for dedication. Public notice of the intention to reserve is equal to that given by a plat. Intentions to dedicate land without supporting evidence or acts signify nothing.

Before dedications become binding on either party, there must be certain proof of the acceptance of the dedication. The acceptance can be actual, expressed, or implied. Until there is an acceptance by the public, the public has no rights and neither has the public assumed any responsibility.

The Doctrine of Agreed Boundaries

When it becomes necessary to ascertain a boundary other than by reference to legal descriptions contained in deeds or other title documents, then agreements between parties may serve as a basis for locating them. Determining a boundary line in this manner will not qualify as a conveyance of property; such an agreement supports the boundary location as intended in the deed of conveyance.

According to the English Statute of Frauds, enacted in 1677 and in force today in the United States, for contracts dealing with the sale of land to be enforceable they must be in writing. Boundary line agreements, by whatever means, do not fall into this category since they are not a transfer of land but an attempt by the parties to fix that which is uncertain. The line in question was established in the past when the title was created, but is now uncertain or unascertainable. The courts sometimes label this as being "in dispute." In order to qualify for a boundary agreement, a boundary must be unknown or unascertainable; otherwise, if it is known and located or placed elsewhere, the result would be the attempted transfer of a small sliver of land, and therefore contrary to the Statute of Frauds. Some states have specific statutes outlining the requirements of how boundary agreements are to be accomplished.

There have been recent attempts in some areas to relocate boundaries, through the use of an agreement, for convenience, or to circumvent the investigative process or undertake a survey, mostly to try to save money or time. Several courts have ruled such agreements ineffective and therefore the title and conveyance as void.[6]

Boundaries by agreement are dependent on a mutual agreement on the boundary location. Boundary agreements entered into by adjoining owners recognize that three legal obstacles must be overcome before such agreements have force. The English Statute of Frauds, adopted by a great majority of the states, requires that all agreements affecting an interest in land must be in writing if they are to be legitimate. Protection of the rights of an innocent third party is a concern. It is essential that they have the same knowledge of agreements as the parties to the agreements. All states accomplish this by maintaining a system whereby deeds are recorded and wills probated. These systems of recording documents must comply with the doctrine of constructive notice. This doctrine requires that other parties may review records that can and often do affect them.

Courts often require that certain factors be present before establishment of boundaries based on such agreements. Boundary agreements must involve lines or corners that are uncertain or disputed. These agreements must set out a specific line as the boundary. Execution occurs by acts of the parties occupying adjoining land, and the agreement must include land to the agreed line. Recognition of the agreement for a considerable period is the final requirement. This period is often equal to that required for adverse possession.

Created Boundaries by Acquiescence

Acquiescence is similar to boundaries by agreement except this type of ownership is unique because it does not require proof that the boundary location resulted from an express agreement. The justification for this ownership is similar to that for adverse possession. For this doctrine to be enforceable, occupation must be visible up to a definite marked line. Typically, a long time must elapse before ownership by acquiescence exists—often the same period of time as required for adverse possession to be perfected.

The case of *Provonsha v. Pitman,*[7] is a good example of establishing boundaries by acquiescence. The disputed tract dated back to 1884. The disputed area was within the metes-and-bounds description claimed by the plaintiff, Provonsha. The area was also included in a deed for 160 acres south of the plaintiff's tract. The area involved in the dispute was 15.1 feet wide at one end, 7.5 feet wide at the other, and 462 feet long. It represented about 5 percent of the plaintiff's land, but was an infinitesimal part of the total land value.

Construction of a barbed wire fence took place in 1898 to divide a 462-foot square block equally between spouses in a divorce action. The fence remained at the time of the trial in 1957. Repair of the fence had occurred over the years and sections had been replaced several times. Ownership of the tracts on both sides of the fence had changed hands many times. Adjoining owners respected the fence and occupied and used land to this physical barrier. In 1935, a new owner had a survey made, which showed the fence to be in error. Neither this owner nor any of his successors in title took any action other than making statements about the erroneous location.

In 1955, the plaintiff sued to regain the disputed tract. He based his claim on the conversations, incidents, and understandings of recent owners. The court found no evidence of anything but occupation and use of the land up to the fence by either of the parties, and therefore said acquiescence established the boundary.

As with adverse possession, ownership may be established through acquiescence so long as the occupation meets the necessary requirements. However, a surveyor must not render an opinion of title, but survey record lines and note differences between them and the occupation. Thus, when acquiescence is a possibility, the surveyor's responsibility is to show the evidence thereof in relation to the record lines. In the case of *Western Title Guaranty v. Murray & McComick,*[8] the court noted that merely pointing out a difference was insufficient and that the surveyor should have made parties aware that there was a marked difference between the record line and the occupied line marked by a fence, and that there may be a question of ownership. In this case, the title company relied on the survey plat and was later found to have insured more than what the client had title to. It was a long, drawn-out series of court hearings amounting to a loss by the insurance company and the surveyor over a conflict of about 19 acres. In such cases, survey plats should be clear about what a client has by deed and what might be otherwise questionable or in conflict.

Created Boundaries by Estoppel

Estoppel is a legal act resulting in a person being forbidden by law to speak against his or her own actions and deeds. It is a remedy that prevents allegations and denials of certain facts previously stated as true.

Boundaries by estoppel come about when the true owner knowingly misrepresents his or her boundary and causes a neighbor to rely on the representation and therefore incur detrimental cost. In such cases the boundary becomes that as represented. Estoppel manifests itself when "a man's own act or acceptance stops or closes his mouth to allege or plead the truth."[9] It is to bar, stop, impede, prevent, or preclude denial of a certain fact. In the situation of boundary by estoppel, the following example illustrates the principle. Should a property owner know that an adjoiner is making improvements next to or along a line that the parties have falsely considered an actual boundary line, then estoppel prevents him or her from later claiming a true line running through the improvements.

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[6] *Lewis v. Ogram,* 149 Cal. 505 (1906); *Myrick v. Peet,* 180 P. 574 (Mont., 1919); *Williams v. Barnett,* 287 P.2d 789 (Cal., 1955).

[7] 6 Utah2d 26, 305 P.2d 486 (1957).

[8] Cal.

[9] *Caulfield v. Noonan,* 229 Iowa 955 (1940).

This situation existed in the case of *Pitcher v. Dove*.[10] In this case, the defendant (Dove) had taken possession of land by a sheriff's deed. Dove had lived on the land before purchasing it at the sheriff's sale. The description called for beginning at a particular corner and running a particular distance and direction. Dove based his claim on running a particular direction to a stone set by the county surveyor. This claim gave Dove a greater distance than called for in the description included in the sheriff's deed.

On a half dozen occasions during this period, Dove and the plaintiff (Pitcher) had physically traced the property lines on the ground. On those occasions, Pitcher had pointed out the stone set by the county surveyor as the corner. He further advised Dove to purchase the land in question. When Pitcher and Dove inspected the property, they found a fence on the boundary line. This fence agreed with the set stone. Pitcher had stated that the fence was on the line. Pitcher later moved the fence to correspond with the call in the sheriff's deed. The court found for Dove, although no mention of the stone appeared in his deed. The court found on the grounds of estoppel. Dove had based his actions on Pitcher's representation of the stone as the corner.

The four criteria necessary for a judgment by estoppel were present in this case. The estopped party must know the facts that form the basis of the estoppel. This party must have acted in a manner such that the second party had a right to believe that he could act on the statements and conduct of the estopped party. The party claiming the estoppel must have no knowledge of facts to the contrary from those represented by the other party. Finally, because of the statements and conduct of the estopped party, damage must have occurred to the person claiming estoppel.

As with adverse possession and acquiescence, extent of ownership may be established through estoppel, but a surveyor must survey the record lines, again noting any differences, conflicts, or discrepancies that may affect the title. Thus, when estoppel is a possibility, the surveyor's responsibility is to show the evidence thereof in relation to the record lines.

Liens and Mortgages

Both liens and mortgages affect property ownership and therefore are concerns when land is in the process of development.

Liens are a claim on property. They occur because of some obligation or debt on the part of the owner of the property. The lien is the means of securing the claim or debt owed to the lien holder. The operation of the law provides a means of acquiring a lien. This happens when the law advances a lien without having the stipulation of the parties concerned. There is a period between the reasons for a lien and the actual filing of the liens.

Title companies often depend on survey reports to point out possibilities from which liens can evolve. Such items as building construction, alterations, and repairs not paid for can result in the filing of material and labor liens. The surveyor should note improvements to street and sidewalks, as they too can be a source of liens. Construction of water and sewer lines are also indications of possible liens. Determination of the actuality of these possible liens is a matter of law and beyond the realm of the survey.

A mortgage is an estate created to secure an act by a creditor. In most instances the act is the payment of a sum of money by the grantor of the mortgage to the grantee of the mortgage. The mortgage becomes void when the grantor meets the terms of the mortgage.

Action for Ejectment

An action for ejectment is a legal action for prevention of possessory interference with a property owner's title and provides a means to test the right of possession. Ejectment has evolved into a legal remedy for the protection of an owner having good legal title. Such an action provides a means of recovery of land only on the strength of the plaintiff's title. One use of ejectment is the settling of boundary disputes before land development. Simply put, ejectment is a suit that provides a method of trying land titles. This, like all legal actions, is usually a long and costly process.

Surveys for Transfer of Developable Real Estate

In 1962 the American Land Title Association and the American Congress on Surveying and Mapping jointly developed and adopted a set of standards for conducting surveys in conjunction with the closing of commercial loans on real property. These standards, the Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys, have been periodically revised and as of the date of this publication, the current version is dated 2005 (see Appendix G).

The ALTA/ACSM Minimum Standards provide for a nationally defined and accepted set of survey requirements. Today they are required in conjunction with most real estate transactions on properties contemplated for development, and, as such, the surveyor and other interested parties should be familiar with them. There is additional information regarding these standards in Chapter 13.

LAW OF EVIDENCE

The combined rules and standards that control the factors determining information and facts presented in legal proceedings compose the law of evidence. The law of evidence regulates the determination of admissibility, relevance, weight, and sufficiency of the evidence presented in a legal proceeding.

Evidence may be defined as "any species of proof, or probative matter, legally presented at the trial of an issue, by the act of the parties and through the witnesses, records, documents, concrete objects, etc., for the purpose of inducing belief in the minds of the court or jury as to their contention" (Black, 1990). Evidence is not proof, but the consideration of all of it as presented and the deduction reached from it

[10] 99 Ind. 175 (1884).

leads to truth. A preponderance of evidence will prevail in civil cases. Not all evidence carries the same weight in establishing proof.

Surveyors should be cognizant of laws pertaining to evidence. If surveyors ignore evidentiary considerations, they may find their work given no weight as evidence in court proceedings. For example, courts have ruled that surveys started at monuments not lawfully established, or reestablished, under the rules of evidence have no probative force. A basic understanding of the law of evidence will prove a helpful tool to surveyors.

Indispensable Evidence

Indispensable evidence, as the name implies, is that evidence necessary to prove a particular fact. The following statement provides an example. Land boundaries based on adverse possession must establish the fact of that possession by presentation of evidence such as enclosures. The surveyor would therefore locate fences that would constitute indispensable evidence of such enclosure.

Undisputed Evidence

Undisputed evidence is conclusive evidence. The clear contents of a written instrument, such as a deed, remain unaltered by oral testimony. When trying to prove the location of a boundary, one considers in high regard those documents that are a part of the conveyance.

Prima Facie Evidence

Prima facie evidence stands court test until rebutted by other evidence. A probated will granting a party ownership to a tract of land is prima facie evidence of that ownership. Proof of the rebuttal of the will would be necessary to contradict such evidence.

Additional Types of Evidence

Other classes of evidence consist of primary evidence, secondary evidence, direct evidence, indirect evidence, partial evidence, extrinsic evidence, and hearsay evidence. Primary evidence is original or firsthand evidence. It is that evidence that is given priority for ascertaining the truth. A copy of a document is secondary evidence because of its inferior position compared to the original document; however, secondary evidence may suffice in the absence of the original, or primary, evidence.

Direct evidence supports the existence of a fact without depending on proof of other facts. The testimony of an eyewitness to an event is direct evidence.

Indirect evidence, on the other hand, requires proof of one fact by proof of another. This evidence is circumstantial evidence because of its dependence on other facts. Evidence used to establish a detached fact is partial evidence. This type of evidence is subject to rejection unless connected to the fact in dispute by proof of other facts.

Extrinsic evidence lies beyond the body of a document for agreements or contracts. Such evidence is primarily for explanation of references in the documents. This evidence can clarify meanings of terms that vary within local context.

Hearsay evidence is not original or does not come from personal knowledge of a witness. This type of evidence comes secondhand, by way of what a witness has heard someone else say. This evidence is admissible in only a few instances. Even in situations where such evidence is permissible, its credibility would be a matter for the jury to decide. Since much evidence used by a surveyor is hearsay (deeds, plans, photographs, parol evidence) it is important for surveyors to be aware of the exceptions to the hearsay rule so as to know what may be useful and what is not permitted.

Exceptions to the hearsay rule may include records from a variety of institutions, certain statements, ancient documents, matters of history, and learned treatises, all of which is secondhand knowledge, or evidence, used by the declarant.

Parol evidence is oral evidence that may be used in certain instances of expert testimony. However, this often depends on the discretion of the individual court, particularly when the actual declarant is available.

Collecting Evidence

The four forms for gathering evidence are oral testimony, written documents, real or material objects, and judicial notice. Oral or parol evidence is that given by mouth by a witness in a court. Another method to obtain evidence is from contracts, wills, deeds, and other types of written documents. Documents presented as evidence are usually self-explanatory; however, witnesses may give testimony to explain ambiguities when they exist or make interpretations where necessary under the appropriate circumstances. The courts place limitations on the types of documents allowed for presentation. This is a matter for consideration when preparing for a court appearance. Real or material objects such as monuments, fences, and other physical evidence are most important in support of the proof of a fact. Judicial notice is the act of recognizing the truth (universally established such as a historical event) related to the facts of a case. This recognition by a court takes place without supporting evidence.

Consideration of Evidence

Other considerations in the rules of evidence include real and demonstrative evidence. The same chapter of the statutory law addresses topics such as declarations and admissions, weight and sufficiency, and questions of law and fact. The understanding of evidence is most important to the surveyor involved in land development. His or her determination on the location of property lines and corners usually provides the basis for development and construction work to progress.

Often a surveyor's work is nearly complete before a legal problem is detected. Should the land under development become involved in litigation, the surveyor's interpretation is subject to admission or rejection in court, depending on his or her adherence to the rules governing the law of evidence.

One author has stated, "Everyone is presumed to know the law and the surveyor is no exception. If he agrees to monument a certain written conveyance on the ground, he also agrees to locate the conveyance in accordance with the laws regulating the interpretations of written conveyances" (Brown and Eldridge, 1967, sec. 2.19).

WATER LAW

Many facets of water law affect land development. Property rights and public rights are the predominant factors that control water management and usage. Navigability distinguishes private rights from public rights. Rights vary depending on whether the water is surface or subsurface. Flowing waters contrasted with those found in a body also affect rights.

Land development requires proper management of water. This management includes surface and subsurface water. Some knowledge of water law is necessary before water resources planning can begin. Failure to consider appropriate water law can be devastating to the land development process.

Water is always in motion. As part of the hydrologic cycle, water exists in varying states, but no matter the state, it is water. The state of its existence can be vapor, rain, snow, dew, surface water, or ground water. A property owner's rights concerning water use depend on a number of factors including whether the water is atmospheric, surface, or subsurface. Laws control the use of water flowing in a stream or existing in a body such as a lake. The laws of riparian rights or those of prior appropriations govern this control. When water seeps into the ground, rules for subsurface flow govern the manner of its control. Yet another set of laws determines the use of water flowing in a dispersed state across the surface of the earth.

When waters are navigable, they become public waters. The problem lies in the determination of what constitutes navigability. The rule often given for this determination is that "if water is navigable in fact it is navigable in law." Recent laws have defined navigability beyond this and based the question on flow. To declare water navigable by statutory law, when that water is not navigable in fact, gives the owner of the water rights due compensation. In most situations, statutory law is more limiting on property rights than is navigability. In situations such as these, surveyors and engineers involved in land development should be familiar with the federal statutory law definition of *navigable waters.*[11]

[11]16 U.S.C. § 796(8). *Navigable waters* means those parts of streams or other bodies of water over which Congress has jurisdiction under its authority to regulate commerce with foreign nations and among the several states, and which either in their natural or improved condition, notwithstanding interruptions between the navigable parts of such streams or waters by falls, shallows, or rapids compelling land carriage, are used or suitable for use for the transportation of persons or property in interstate or foreign commerce, including therein all such interrupting falls, shallows, or rapids, together with such other parts of streams as shall have been authorized by Congress for improvement by the United States or shall have been recommended to Congress for such improvements after investigation under its authority.

State laws, as well as federal laws determine the water rights of an individual owner. States base their laws on two fundamental, but different, doctrines. The two doctrines developed to control water uses are riparian rights and appropriations. In most instances, the courts have integrated and modified these two fundamental doctrines to develop many of today's current water laws.

Riparian Rights

Riparian owner's rights include use of the water and encompass those rights for the enjoyment and development of his or her land. Issues and lawsuits related to riparian rights are much more common in the western states, where water resources are scarcer, and thus more valuable, than in the eastern states. These rights of use must not infringe on the rights of other riparian owners to exercise those rights. If all riparian owners have the same rights in the same body of water, then the use must be reasonable by each owner.

The property must adjoin a natural watercourse for these rights to exist. Additionally, the land must lie within the watershed of the riparian waters for riparian rights to exist. Once severed, these riparian rights remain lost from the land, and the loss is a permanent one. The term *littoral owner* indicates a particular type of riparian owner. A littoral owner is one who adjoins a body of water such as a lake or sea. The rights of a riparian owner include access to the water.

Other rights include extraction and use of the water. The riparian owner can only preserve the water in its natural condition. The following example illustrates unnatural use of water. When a riparian owner takes water from a river for use in a cooling process at a canning factory belonging to the riparian owner, the result is "unnatural" if the water temperature is higher when returned to the river than when first removed from the river.

Riparian owners, in most situations, have rights to all the water necessary for domestic purposes. Upstream owners have this right of use even if it deprives lower riparian owners of water required for that use. This domestic use includes water for the care of livestock but not for use by cattle raised for commercial purposes.

Riparian rights give to the owner of those rights the use of water in riparian watercourses for irrigation. The "reasonable use" rule and the claims of each riparian owner declaring his or her rights to those waters restrict the usage of each.

The conduct employed by the parties provides a test of the doctrine of reasonable use. The test, when applied by the courts, resolves conflicting rights of riparian owners. Temporary interruption in normal flow of riparian waters usually does not constitute grounds for liability for damages. The validity of this depends on the circumstances involved and the jurisdiction where the case occurs.

When riparian waters are navigable in fact, the public has a right to use the water for recreational purposes. This further modifies and limits the rights of the riparian owner.

Should the body of water change course gradually and imperceptibly, leaving land exposed, the riparian owner may gain property rights to this newly revealed addition. Such a process is called *accretion* or *reliction*. The precise definition of the term *accretion* is "a gradual and imperceptible accumulation of land." Soil deposits left by the body of water attaching to the accreted land result in this increase. *Reliction* is a process that exposes the land previously covered by water. This exposure occurs by a gradual and permanent subsidence of the water. Ownership or title lines move with the shifting shoreline under the proper conditions. *Avulsion* is a term that describes the sudden and abrupt change in a land formation. This action may be the result of an act of God. Such changes do not affect boundary locations and thus are different from accretion or reliction.

Surface Water

In most cases, water classified as surface water allows for its consumption by the owner of the property on which such water exists. The disposal of this water can pose problems, particularly in land development projects. Under early legal doctrine, landowners could dispose of unwanted surface water. Such disposal could take place artificially without incurring any liability from neighboring landowners. The legal name applied to this doctrine is the *common enemy* rule. Under this doctrine, adjoining landowners could protect themselves from surface water by any means available.

In some states, this rule still applies to surface waters that naturally drain from one property to another. The majority of the states have modified this rule. These modifications mean that only reasonable changes can take place, without liability, in the flow of these surface waters. Under the modified rule, land developers are not liable to adjacent owners for increases in runoff.

Other states do not follow the common enemy rule but follow instead the civil law doctrine. This doctrine allows surface waters to flow from one property to another if that flow is in a natural channel. Owners of lower-lying property cannot obstruct this flow. The downstream owner may take reasonable steps to protect against this flow. Landowners may seek protection under a modified version of the civil law doctrine. Combining this doctrine as modified and the common enemy rule as modified results in a reasonable use doctrine.

The degree of harm inflicted on the downstream owner and the foreseeable harm, good-faith, and cost-benefit factors furnish the criteria used to judge reasonable use.

Subsurface Waters

These waters include percolating waters, underground streams, and artesian waters. Under common law, the surface landowner has the absolute right to extract percolating water. This right exists without regard to the impact on adjoining owners. Many states modified this law into reasonable use. Bordering landowners share rights under this doctrine. The same rules of law as those that control surface waters control underground streams if both lie in the same government jurisdiction.

When following the common-law rule, the surface owner has absolute ownership of percolating water. Landowners have corresponding rights in the percolating waters when the rule of reasonable use controls the jurisdiction of land ownership. The doctrine of prior appropriation gives ownership of the percolating water to the state. The water is available to surface owners based on respective state laws.

Landowners may become liable for obstructions in the flow of percolating water. Extremely hazardous activity that causes interruption of flow would likely cause such liability. If the surface owner acts in a nonnegligent manner while in the process of developing his or her land, then such acts carry no liability for damage to percolating water.

Differing views exist concerning the liability of a surface landowner. Responsibilities and rights in subsurface waters related to the surface owner might also hinge on the type of subsurface water involved (percolating waters, underground streams, and artesian waters). When a surface owner pollutes percolating water, he or she usually incurs liability related to the manner of the use. If the surface owner uses the land rationally, he or she will incur no liability for these actions. This often holds true even when these actions result in injury to another landowner. The surface owner can incur liability if the land use is reasonable but the use was negligent on this owner's part. Some government authorities hold landowners liable for pollution regardless of the manner of their use. Owners can become vulnerable to claims without the presence of negligence and unreasonable use of the land. When this situation occurs, liability exists without fault.

The question of "reasonable" and "negligent" or "unreasonable" obviously can become a matter of hairsplitting. Complications in interpretation of water law also arise because of variations of interpretation between jurisdictions. The following court rulings shed some light on the dilemma involved in making a determination relative to usage. A case from the Arkansas court illustrates the reasonable use of ground and surface water. It should be noted at the onset that Arkansas is a riparian rights state and follows a modified doctrine that includes reasonable use. The case used for illustration is that of *Jones v. OZ-ARK-VAL Poultry Co.*[12] The Arkansas Supreme Court ruled that reasonable use applied to all underground waters as well as those on the surface. In this case the court went further and accepted the correlative rights doctrine set fourth in *Hudson v. Dailey.*[13] Correlative rights further modify the rule of reasonable use to a proportionate share of the underground water to the surface landowner in times of short supply of the water. In effect, this ruling indicates that reasonable use of water relates to available supply. Therefore, as supply changes what has been reasonable use can become unreasonable. As with all situations under law, each case involves circumstances peculiar only to the case at hand. It is not the intention to imply that a rule exists for the determination of reasonable versus

[12] *Jones v. OZ-ARK-VAL Poultry Co.*, 228 Ark. 76 (1957).

[13] *Hudson v. Dailey*, 156 Cal. 617, 105 (1909).

unreasonable. The intent is to point out possible pitfalls that might arise out of the land development process.

LAND USE

In a chapter dealing with property laws, it is appropriate to include a section on land use. Ownership of property relates closely to the right to use that property. Laws controlling those uses are worthy of mention in this section.

All phases of land development should begin with extensive planning. The first step in the planning process, preceding the technical planning, is a market analysis. This study can be the difference between success and failure for any development. A need assessment can determine the type of development having potential for success and the design suited for the site location.

Land and site planning involve evaluation of the site. Locations of specified land uses occur during this part of the planning process. Topography and access play a major role in these determinations. Engineering and surveying follow as they become necessary for the precise location of items set out in the planning stage. Most municipalities require engineering plans before site development can begin. These plans show street grades, earthwork, stormwater drain lines, sanitary sewers, utilities, and water supply lines. Also incorporated into these plans are material schedules necessary for the development's construction.

Planning and designing buildings requires the services of an architect early in the development process. In many instances, the architect can help with site planning. The architect assists in overall coordination of style used within a land development project.

If the planning process is to proceed in an orderly manner, all participants must consider legal implications. Legal topics discussed to this point are common to all property surveys. When a land development is pending, then legal topics related to that development become important factors. They can affect and control the planning and construction process.

Land Use Regulations

Common law and statutory law provide for the regulation of land by private and public means. Private land use regulations, such as recorded covenants, usually exist through arrangements entered into by private parties. Laws and courts provide for enforcement of these arrangements.

The law of nuisance also provides a form of private regulation. Nuisance law pertains to the control of "that which annoys and disturbs one in possession of his property, rendering its ordinary use or occupation physically uncomfortable" (Black, 1990, s.v. "nuisance").

The law of nuisance is a doctrine that, while allowing a landowner to make reasonable use of his or her land, does not allow a landowner to deprive other landowners in the community of the reasonable use of their land. Enforcement of nuisance laws usually results from the actual physical activity causing the nuisance. The greater the physical impact on the land, the greater will be the possibility of the court granting relief to the affected party.

Public regulation of property is achieved through zoning laws. Governments possess, as an incident of their police power, the ability to regulate the use of land to safeguard public health and welfare. Particular land use zones established under zoning ordinances regulate land use.

Ordinances

Ordinances are laws initiated by authority of a local legislative body such as a county board or a city or town council. Local governing bodies adopt subdivision ordinances to provide for a healthy living environment. These ordinances set up specifications that produce better design of the building lots while providing control over the creation of new lots. In many jurisdictions, an unsubdivided portion of a master lot cannot be conveyed to a new owner. In some cases, an unsubdivided portion can be conveyed, but only under strict guidelines that, for example, might limit the size of the parcel being created. Thus, subdivision and the creation of new lots are required to allow more individuals to become landowners.

Restrictions

Restrictions can exist in the form of deed restrictions and restrictive agreements. Zoning laws are but one form of restriction. Grantors cannot pass title to rights that they do not possess but they have the option of disposing of fewer rights than they possess. When grantors choose to do this they may destroy these rights, or in some cases they may retain them for themselves. Clauses in deeds that place limits on rights are restrictive covenants. Most often these clauses are not restrictive but, rather, offer protection. If written for the community, these restrictions protect against undesirable use of the land.

Restrictions are either public or private control over the use of property. Simple examples of each follow. A private land developer purchases a tract of land and employs professionals to subdivide it into some smaller parcels. The surveyor or engineer will map and properly record the subdivision. A note on the face of the map designating all lots for residential use only is an example of private building restrictions. A city or county zoning ordnance that sets a particular area aside for industrial use or other areas residential use is public control.

Courts provide means of enforcing restrictions. The party seeking to enforce restrictions can petition the court to issue an injunction (order) to halt the violation. Anyone found to be in contempt of such an order is subject to contempt of court sanctions, which may include incarceration.

Subdivision Development

Subdivision, broadly defined as the creation of smaller lots from a larger tract, falls under the jurisdiction of a local authority in most states. Subdivision regulations, however, differ widely among local jurisdictions, and surveyors should be well acquainted with these local ordinances.

There is a tendency to think of subdivision development as a relatively new process. Shortly after the Norman Conquest of 1066, William the Conqueror established a form of subdivision control in England requiring permission from the Crown for divisions of baronial estates. History shows this activity to be one of the earliest forms of man's social coexistence with other men. Subdivision development and new cities on this continent trace their existence to the first settlements. The Royal Ordinances for the Laying Out of New Cities, Towns or Villages, circulated by Phillip II of Spain in 1573, is an example of early regulations intended to control land development. Many early town charters provided for methods of laying out church sites, town markets, streets, and lots. Colonial charters also controlled subdivision of lands for new towns. The Continental Congress regulated the division of western lands through the adoption of the Public Land Survey System.

By the nineteenth century, earlier subdivision and land controls, together with the exploitation of the land by developers in "get rich" schemes, led to further regulation, requiring accurate surveys and maps of proposed subdivisions and regulation, in many states, of street width and alignment. Before lots could be sold, local officials were required to verify surveys and maps. Public official review and approval of public dedication of streets was also required before lot sales could take place. The public dedication requirements and procedures became clearly established.

In 1928, the U.S. Department of Commerce published the Standard City Planning Enabling Act (Standard Act). State legislative acts followed, and by 1961, nearly 1000 cities with populations more than 10,000 had developed comprehensive subdivision regulations. Today, all 50 states have adopted some form of enabling legislation concerning subdivision law. Land developments are subject to more stringent controls than at any other time in history.

Subdividing land is not as simple as completing a survey and preparing a map that includes lots and streets. Subdivision regulations mandate the laying out of streets and dividing land into blocks and lots. For the process to be beneficial and orderly, subdivision laws must be enforced in accordance with their tenor and not interpreted by political sentiment. While civilization exists, new land developments will begin and old land developments will expand.

Today, subdivision control goes beyond the size of lots and the horizontal and vertical requirements for streets. These controls also surpass the requirement of installing on-site roads, sidewalks, water and sewer lines, drainage, and other utilities. Some jurisdictions now require dedication of land for parks, schools, sewage treatment plants, and other public use, providing a sufficient nexus exists between the dedications demanded and the impacts caused by the subdivision.

Many courts have upheld requirements for such dedications. One city required that 4 percent of the land development area be set aside for parks and playgrounds. One court said this requirement was reasonable and upheld it because the new development created the need for the park and playground.[14] The limit on the amount of such dedications and exactions allowed by law in the subdivision process differs greatly between states and between different jurisdictions in a state. In a recent case, the Supreme Court of the United States has ruled that a "rough proportionality" must exist between the exaction sought and the slated public purpose involved.[15]

Recent land development regulations address environmental concerns. These controls often require the developer to submit project plans to a government agency. This agency will grant approval if there is no indication of adverse impact on the environment. The State of Vermont has adopted a new land development law administered by the Environmental Control Board through seven environmental district commissions. Developers must obtain permits for proposed subdivisions from this board. This law is an example of the tendency in land development controls to curb negative environmental impact.

The approval process for subdivisions varies from one place to another, but the overall procedure is much the same. First, review and understand the local subdivision ordinance. Second, survey the land to obtain an accurate description of the boundaries. Third, proceed with surveys to locate abutting streets, determine topography, and locate special features. Fourth, locate any structures and easements existing on the site. Fifth, determine any restrictions imposed on the property.

Water lines that serve the subject property should be located if they exist. State and local requirements for sanitation disposal and provision of potable water should be determined. Information on water table heights, soil conditions, and prevailing wind directions is important. This information may affect lot layouts.

The surveyor should check subdivision ordinances for restrictions. They often include lot size, setback lines, and other specified items. In addition, the surveyor should review the local zoning ordinance for other limitations. Subdivision regulations typically control street width and grades. The ordinance usually includes the procedure for presenting maps and plans to the controlling government body.

The developer should employ an engineer or surveyor to prepare preliminary plans for the proposed development. The local subdivision ordinance provides a guide for the preparation of such plans. These plans should show the approximate size and shape of the proposed lots. The preliminary plans include street locations, street grades, and the method of providing drainage for all areas within the development. These plans also indicate land use, utilities, and zoning.

The surveyor should locate public facilities such as schools, parks, and playgrounds and record distances from these facilities to the proposed development site. Available transportation and shopping facilities affect the needs assessment. Cost estimates determine the feasibility of the proposed development. Sound developments usually depend

[14] *Aunt Hack Ridge Estates Inc. v. Planning Commission,* 160 Conn. 109 (1971).
[15] *Dolan v. City of Figard,* 114 s. Ct. 2309, 2314 (1994).

on investment moneys for home mortgages and development cost including streets, utilities, and earthwork.

Various agencies require filing of proposed development plans. The local planning commission is the coordinating agency in most localities. After approval of the proper agencies, the development can proceed. Submission of a final set of plans to proper authorities usually precedes lot sales.

Shopping Centers

Land use for commercial purposes covers a broad range. It includes the regional financial center through the small central business district down to the smallest commercial unit, called the *neighborhood center.* Each of these units must meet a specific need. Controlled designs of this type include provisions for traffic, parking, and floor space. The type of center determines the appropriate balance between these factors.

Centers can be categorized by the population they serve. Neighborhood centers serve between 7,500 and 20,000 people. Community centers provide more variety in service and reach a population in the 20,000 to 100,000 range. Regional centers are complete with major department stores and serve a population from 100,000 to 250,000. A thorough analysis should precede the building of any center to provide for needs assessment. This analysis is typically performed by the real estate developer, who often assembles the necessary information from several consultants, one of whom may be the surveyor.

Most neighborhood centers require approximately 5 acres of land for the site. Sites for community centers are larger and often are 10 or more acres in area. Regional centers are around 30 acres. Consult local regulations for definite control of zoning and restrictions.

Industrial Parks

These subdivisions are a very specialized type of development and require special knowledge of industrial requirements. Today these parks serve a community in much the same manner as the industrial districts of earlier times. Such parks are not suitable to all industries.

These parks offer benefits to industry and communities. Industrial parks can relieve industry of legal problems stemming from zoning. The site offers utilities and other services; therefore, the industry encounters no problems from local government in securing such services. Often there is a significant reduction in site development cost to the industry that locates within such a park. There are other beneficial factors available to industries that locate near each other, including security, eating facilities, and clubs for employees.

Industrial parks, as is true with most subdivisions, must have a set of protective restrictions. These take the form of covenants carried in deeds and leases. They help ensure compatibility among occupant plants and between the park and the local community. Standards must be sufficiently high to be acceptable to the nearby residential communities. They must not be so rigid that they become unacceptable to the very industries sought by the park.

Properly developed and administered restrictions can make land usage predictable and therefore protect property values in the park and the area surrounding it. Protective covenants in most industrial parks regulate both permitted and prohibited uses. They control emissions of smoke, noise, heat, industrial waste, light, odor, and other environmental factors. Included in typical restrictions are such items as site size, site coverage, building line setback, parking, building, and construction types.

The communities that house industrial parks reap benefits from the diversification of the local economy. A broader tax base, more income into the community, and a general stimulant to the area are all benefits that come with successful industrial parks.

City-County Planning and Zoning

City and county planning processes are as old as the governing bodies themselves, but zoning processes are of twentieth-century vintage. Past planning may or may not have been as good as that seen today. Modern urban planning and zoning processes leave these roots in the Standard City Planning Enabling Act of 1928. Tomorrow's generations will criticize today's planning in a different light because planning is forecasting, and forecasting is difficult. In the past, forecasts have tended to underestimate growth in our cities. This has created many of the problems seen today. It has also made solutions to other problems difficult and more costly to solve. At the root of city and county planning is the plan for an adequate transportation system, and as this system becomes more complex, the planning process must become more comprehensive. Good planning meets the demands and problems of the present.

One objective of the planning process includes increasing economic efficiency by coordinating the size and location of physical facilities with projected future needs. Planning should provide an overall design for urban expansion that is aesthetically pleasing and retains the natural integrity of the land. The planning process also serves to allocate land to varied uses necessary for stable and healthy growth. Properly executed planning enhances the relationship among various land uses.

A major factor in the planning process is control, and a U.S. Supreme Court ruling has qualified zoning laws as an essential part of such controls.[16] Planning and zoning commissions exert control over subdivisions and other land use areas surrounding cities. The land developer has the opportunity to produce well-planned land developments; however, he or she needs the help of a land-planning team composed of engineers, surveyors, architects, and land planners.

Zoning is a plan or process that, as the term suggests, divides a city or county into zones. Each of the designated zones serves a particular use. Provisions for zoning ordinances come from the state's police powers. These are necessary to protect the health and safety of the public. Such

[16] *Warth v. Seldin,* 422 US 490 (1975).

zoning prevents overcrowding, establishes appropriate sanitary regulations, provides for a more efficient transportation system, and protects quiet residential areas. For example, zoning lessens the danger of fires by banning factories from residential districts.

Zoning ordinances were simplistic in the beginning. Division of a city into three zones—residential, commercial, and manufacturing—was usual. Trends in zoning are evolutionary, and modern ordinances create more classifications. Residential districts are no longer exclusive to single-family dwellings but provide for multifamily dwellings as well. Subdivision of commercial zones into retail and wholesale areas is usual. Subclassifications used in industrial zones are *heavy* and *light*.

Zoning is exclusionary by its nature, and the courts have ruled that zoning that excludes a class is unconstitutional. Some examples of these exclusions are apartments, mobile homes, and even zoning exclusively for large lots. Some courts have held valid those ordinances that specify minimum lot sizes, but these requirements must be reasonable and must be for the health and safety of citizens. The courts have been consistent in ruling that the exercise of zoning powers is impermissible if the result renders land economically useless. Variances in ordinances allow flexibility and prevent hardship on landowners of particular tracts. This is true for tracts that can be shown to be unsuitable for a certain zone. Ordinances also provide for nonconforming uses, which are uses in existence at the time of conception of an ordinance that conflict with the uses established by the new ordinance for the affected property.

Zoning can be for aesthetic purposes. Bulk zoning regulates the size and shape of buildings and their location on a property. Zoning ordinances usually require property owners to obtain building permits before erecting any structure. Applications must accompany plans and specifications. It is through these permits that enforcement of zoning takes place.

SUMMARY

It is the intent of this chapter to provide a brief overview of legal topics that often affect land development. The section on use of law libraries should provide a foundation for readers to carry on specific research in those areas of individual interest. This chapter is not a substitute for legal counsel and should not be used by nonlegal professionals as a basis for providing legal opinions or legal analysis, or as encouragement to engage in the unauthorized practice of law. Further, this chapter is a supplement to Chapter 13, "Boundary Surveys for Land Development."

Real property and the law controlling and protecting the individuals' rights in that property are at the root of our democratic way of life. Under our system, classification of rights of ownership and defining the limits of that ownership, as these limits relate to the classification, provide order and structure to real property ownership. Instruments such as deeds provide proof of rights held in property. Additional rights that guarantee full usage of property include easements, water rights, and other items. These provide for greater enjoyment of land ownership. All these topics become vitally important under our system of laws and holding of real property.

Orderly progress in land development rests on the system of land ownership provided for under the laws related to such ownership; however, some areas such as zoning and planning can, on occasion, impede development.

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CHAPTER 7

COMPREHENSIVE PLANNING AND ZONING

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Updated/Revised: Silvia D'Jaen Silverman, AICP

INTRODUCTION

Prior to the land development consultant putting pencil to tracing paper and, hopefully, before the land developer's signature appears at the bottom of a land purchase contract, both parties must understand the effect of local planning, zoning, and other regulations. Planning and zoning standards and controls adopted by local government affect everything from the uses allowed on a site to the drainage of stormwater. In some jurisdictions, even the amount of traffic generated by the development is subject to detailed review and regulation.

Under our federal system of governance, where states control all powers not granted to the U.S. government under the Constitution, local land use regulations are the product of what is permitted by state planning enabling legislation. This legislation pertains to the kind of land use regulatory powers local governments can exercise. Given the differing state enabling legislation, local governments operate in different ways. Much of this diversity results from the size of the jurisdiction, the structure of its government, and the legislative authority granted by the state. In addition, each jurisdiction has unique problems and priorities. Residents have varying levels of affluence, sophistication, and involvement within their community and government. These factors impact the way local governments regulate land development.

Even within a single region, the land developer and land development consultant may operate in several jurisdictions. Consequently, they will encounter a broad variety of plans, ordinances, regulations, policies, and procedures, all of which can affect project design, economics, and plan approval. Figure 7.1 depicts the Washington, D.C., metropolitan area surrounded by two states, Maryland and Virginia. Each state operates under a different legislative process and constitutional mandate. Within those two states, there are 13 adjacent or nearby counties, four major cities, and a significant number of independent towns and villages of varying sizes. Due to the post–World War II growth in the region, several once-rural counties have become integral parts of the region. The merging of the Washington and Baltimore economic regions and advent of commuter rail have dramatically expanded the market boundaries within which a Washington developer can reasonably operate. Metropolitan-based land development and building companies now reach as far west as the eastern panhandle of West Virginia, south to Richmond, north to the Pennsylvania border, and across the Chesapeake Bay Bridge to undertake new projects. Each of the jurisdictions of the region is unique in its economic base, its citizens' attitudes, and its government's priorities. Perhaps more to the point, each of these jurisdictions, within the metropolitan area, has its own unique set of planning and zoning regulations. The breadth and expansion of the Washington market are not unique; similar situations exist in most metropolitan areas.

Differences in government budgets and the size and sophistication of review staff and commissions also have broad implications for the development team. These differences affect not only the number of public officials and agencies the development team must come in contact with but also the level of scrutiny given to the proposed rezoning documents or development plans. As the government's size and structure grow so does the potential for conflict between its administrative and elected officials. Each official or department manager reviews rezoning and development proposals

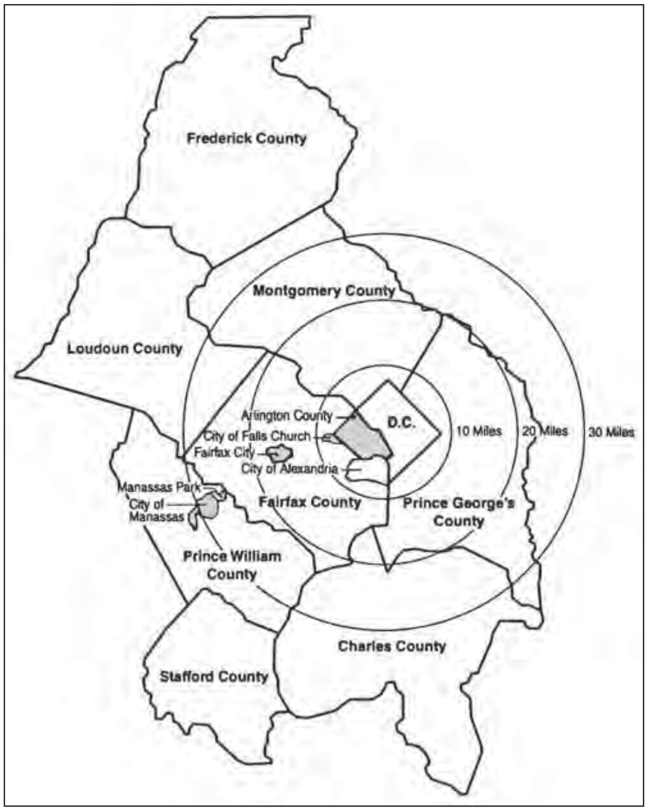

FIGURE 7.1 Jurisdictions in the Washington, D.C., metropolitan area.

with a different constituency or agenda in mind. Each has competing needs and generates competing conclusions. This bears directly on the time it takes to secure zoning approval.

As a jurisdiction matures, political or civic leaders often demand more exacting standards for development and construction. The government responds by tailoring zoning regulations and procedures to address new priorities. Sometimes these new rules and standards take effect even while a proposed zoning project is well under way. These new standards and/or regulations, coupled with increased review time and sometimes circuitous approval procedures, can increase the future land development costs dramatically. The land development team must frequently adjust design and construction budgets during the rezoning process as well as throughout the life of the project.

In an attempt to minimize the risk associated with mistakes made due to lack of knowledge of the development process, it is not uncommon for land developers to specialize in several locations within a region, while avoiding projects in other jurisdictions. Decisions to avoid certain jurisdictions may be made because of market characteristics, unfavorable tax rates, or restrictive development regulations. However, it is increasingly rare for all but the smallest developer to operate within a single jurisdiction.

Given these differences, the land development consultant must become familiar with the land use planning and zoning documents and regulations in effect in each jurisdiction within which the company operates; otherwise, plans and/or proposals may not win government approval. It is the consultant and the land use attorney to whom the developer looks to be experts on local policies and the controls applicable to each new project. Even consultants with prior local government work experience must keep track of newly evolving priorities, policies, regulations, and standards. Furthermore, as government workload increases and operating funds decrease, development review staffs are forced to limit their efforts to technical review. They are unable to devote considerable time or energy to shepherd applicants through the jurisdiction's regulations or review procedures. This places a heavier burden on the land development consultant to develop independence and expertise in the local land development review and approval process.

Developing a clear understanding of local plans, policies, and requirements may seem a monumental task. It is impractical for one person to be sufficiently familiar with all local regulatory programs in the region. To do so would require extensive research into past practices and countless hours in government boardrooms. Acquiring an overall familiarity with the basic structure of government function and regulations makes it easier to assimilate this information. However, effective land development consulting firms designate team leaders with extensive local experience. Each of these people becomes responsible for knowing and monitoring development and regulatory activity within the jurisdiction in which the firm maintains a presence. Absent a clear understanding of a community and its attitudes and politics, the land development process can become a frustrating exercise, with false starts and blind alleys that can prove costly to both consultant and developer.

This chapter addresses only the most typical planning and zoning regulations, ordinances, and procedures. As mentioned, it is neither practical nor possible to address all variations that exist throughout the nation. However, there are basic similarities in the structure of each type of regulation. This text focuses on their differing impacts on land development and the manner in which regulations or procedures are implemented.

COMPREHENSIVE PLANNING

The comprehensive plan, which is sometimes called the master plan or general plan, serves as a formal statement of the community's goals and objectives. The plan establishes policies and procedures relating to the community's future growth, including new development of land and maturation of existing neighborhoods; it represents the collective input of public- and private-sector attitudes, needs, and desires. Its recommendations are based on extensive analysis of economic, social, demographic, and environmental as well as other forces evident in the community and attempts to provide an adopted vision of the community for some distant point in time, typically 10 to 20 years. The comprehensive plan provides valuable guidance for those making important economic decisions, including local officials, land developers, existing and prospective residents, employees, and business operators. Also note that, in most states, *the comprehensive plan is a guide that is advisory in nature and not a legally binding regulation,* such as a zoning ordinance, which indeed is law. However, in a minority of states, the comprehensive plan is directive in nature, requiring conformance, and rises to the level of being law.

To government officials, the comprehensive plan serves several purposes. It defines a general pattern of projected land use for the community. It recommends policies that alternatively encourage desired development or discourage inappropriate uses or intensity of development. The plan establishes and reinforces community standards for appearance, design, delivery of public services, and protection of the environment, and serves as an important guide for allocating resources used for the provision and distribution of public facilities and services. The overall objective of the comprehensive plan is to establish and achieve goals that result in a high quality of life for both the residential and the business communities.

Land development, infrastructure management, and the operation of community services involve extreme public, private, and personal investment. As a result of this investment, the court systems have placed increased importance on the comprehensive plan as either a guide for development *or* a binding source of legally mandated land use regulation. Therefore, most local officials rely heavily on the plan. Its recommendations form the basis for making reasoned and predictable decisions about land use and budgets, rather than those that might be challenged in the courts as arbitrary and capricious.

To the community's residents, the comprehensive plan represents a blueprint for the quality of life they can anticipate. It creates identity for the neighborhoods in which they live and defines the services they expect to receive. The decision to move to a community and purchase a home is perhaps the most important of personal investments made and the comprehensive plan is viewed as a way to predict the soundness of that investment. It identifies the location of new neighborhoods, office and retail centers, new roads, and schools that may affect that investment. The plan provides a way of anticipating intrusion or impacts that could reduce property value with relative certainty.

For the business sector, the comprehensive plan is an essential source of information on potential new markets. The future locations of new centers of employment or residential communities are particularly important to businesses operating support, supply, and service establishments. The plan provides information that can be used to determine the potential customer base available to the business community. Large employers in need of properties with room for expansion also rely on the comprehensive plan for guidance. Existing and future labor forces and sales markets can be determined from the comprehensive plan. At the same time, businesses and employers look to the plan for an expression of long-term commitment to business and economic development. Much in the way that residents look to the plan as an indicator of long-term investment value, the land developer also views the comprehensive plan as a protection of property value. More important, however, the developer uses the plan to identify new opportunities. The developer is in the business of converting raw or underutilized land to new uses. The land development consultant and the developer use the comprehensive plan to determine the suitability of purchasing specific land for new projects based on the planned land use and their particular development program.

Many land developers specialize in a specific land use and product; therefore, the plan is an important tool in identifying the area, and sometimes the specific parcel(s), that are best suited for the particular development program being pursued. The availability of public facilities and services is an important part of identifying the potential of a property. Similarly, the compatibility with and impact of adjacent uses are important factors in selecting property for development. Just as a homeowner is concerned with the neighborhood, so too is the developer concerned about the character of the community. For example, a luxury office developer may not believe that an adjoining industrial or warehouse facility is a suitable neighbor. The plan helps define the market area of a site. The developer uses this information to determine whether there are sufficient employees, residences, or customers to make the project a successful venture.

As the developer's agent, it is the responsibility of the land development consultant to understand the comprehensive plan and its various components. The consultant must also be familiar with the planning process itself. The information used in the plan development process and the events that lead to its adoption form an important foundation for project design. The consultant must understand not only the impact of the plan's recommendations to the land use, but how the jurisdiction will enforce its recommendations.

The plan provides other critical information without which the application of other regulatory tools could be meaningless. This information relates to general design requirements imposed on a project beyond simple use and scale. These include conditions for reducing environmental and service impacts of the development. The plan also aids the developer, by projecting when public and private infrastructure and services will be available to the site.

Community Planning: A Participatory Process

Since the plan is intended as a reflection of the community attitudes and desires, the process usually involves several opportunities for citizen participation and input. The process that some municipalities follow to adopt or revise a comprehensive plan is often lengthy and controversial. Even when this is not the case, it is important for the land development team to become involved in that process. Whether or not projects are under way or envisioned, it is important to be a participant in the process, as the results will shape or constrain development opportunities for years to come. In many jurisdictions, outreach to citizen groups, such as homeowners associations (HOAs) or business associations, has become increasingly common and important in the creation of a plan that is more representative of the wishes of the community and less contentious at the mandated public hearings. Charrettes sponsored by local authorities, city council, or community association meetings are all vehicles for public participation. The information gathered and attitudes voiced are invaluable resources for preparing future proposals.

Although in some cases a close monitoring of the planning process is sufficient, full participation in the process may be preferable. As residential citizens of the municipality and as members of its business community, the team's input is a critical and rightful component of community thinking. The policies and subsequent regulations and procedures that the plan will recommend must reasonably coincide with development practice and not serve as a hindrance to future success. Where communities are encouraged to accept the practical expertise offered by development professionals, the plan and its policies are more effective in achieving the community's goals.

Most medium- and large-sized municipalities employ a professional planning staff, which coordinates the overall planning effort, while smaller communities often retain outside consultants for this purpose. The governing body relies heavily on the recommendations of its planning staff, although decisions about the plan and policies will ultimately be its own. A timetable for the plan development or revision and a framework for the analysis will be prepared. Sometimes working with an ad hoc task force created for the sole purpose of dealing with a particular development issue and composed of the community's civic, business, and political leaders, the staff undertakes extensive data collection. The staff compiles the demographic and economic inventory statistics needed for the analysis, as well as reviewing existing development patterns and activity.

The comprehensive planning process often provides for a period of open nominations, during which citizens can suggest new or revised development policies and specific parcel recommendations for inclusion in the plan. For the land development design team, this is perhaps the most important part of the planning effort. During this period, it may be possible for citizens to recommend, and the governing body to consider, new or revised land use designations for properties under the control of the developer. This could result in a *downplanning,* also known as down-zoning or reduction in the land use density or development intensity recommended in the comprehensive plan. Conversely, this forum provides the land development design team with the opportunity to suggest a different and, perhaps, more intense use of the property and strive to have the comprehensive plan recommendation revised accordingly. Depending on existing parcel zoning, future projects could be drastically altered if development intentions are not confirmed or defended by the land development design team during this nomination period.

As stated, this nomination period also provides an opportunity for citizens as well as landowners to introduce new proposals for future development of the holdings of the developer. Circumstances unforeseen in prior plans, such as expansion of an airport, revitalization of a business center, decline of a neighborhood, or influx of new industry, may justify a change. Similarly, assembly of smaller parcels into a large development tract may also suggest an opportunity for a project of grander scale than anticipated in the plan. The planning staff and other involved groups consider these proposals in preparing the plan. Supporting documentation and testimony presented by the development team form an important component of the analysis.

As the planning staff prepares preliminary drafts of the comprehensive plan, the governing body often schedules town meetings, informal public hearings, or similar forums to allow public input and comments. The purpose of these meetings is to gain a sense of the community's reaction to the plan. Frequently, the planning staff compiles testimony and comments presented at these meetings and responds with an analysis of issues and conflicts. As the process draws to a conclusion, formal, statutorily mandated public hearings are held by either or both an appointed planning commission or similar board and the governing body of the municipality. Throughout these hearings, the information presented by all segments of the community provides an important record on which to base subsequent land development decisions.

Depending on the size of the community, the entire process can take several months to several years. To spread the demanding workload, many municipalities update their comprehensive plans, or portions of it, on a cyclical timetable. Some states' legislation mandates the time within which the jurisdiction must review and update the comprehensive plan, such as every five years. Opportunities for property owners to seek out-of-turn or off-schedule plan amendments may be limited; for further discussion see Chapter 9. The land development consultant must be familiar with local practice to advise development clients properly.

Composition and Characteristics of the Comprehensive Plan

Most comprehensive plans consist of six major parts:

1. Statements of the community's goals and objectives
2. Inventories of its existing characteristics, features and resources, land uses, and facilities
3. Projections of trends expected within the life of the plan
4. Text describing policies to be applied in order to achieve the plan's goals
5. Maps and text depicting and discussing the community, and showing current and future land use, the location of future public facilities, environmental resources, and other features
6. Implementation, text describing how the community intends to carry out the goals of the plan

The statement of goals and objectives is a reflection of attitudes toward the elements that interact to form the built environment. Typically, these elements include the following:

- Population
- Housing stock
- Employment data
- Retail activity
- Industrial output
- Transportation
- Recreation and open space
- Natural and historic resources
- Public utilities, services, and facilities

Many communities add goals addressing the following:

- Economic development
- Social or human services
- Historic and environmental preservation
- Major institutional uses, such as airports, higher-education facilities, and large-scale military or government installations
- Other important indigenous issues or land uses, such as agriculture, mineral production, or maritime activities
- Intrajurisdictional and intraregional relationships and responsibilities

As comprehensive plans are updated, goals are changed to reflect new thinking and new trends in urban design and development. In recent years, with the growing awareness of limited natural resources and scientifically supported evidence of global warming, localities have increasingly included goals or objectives related to sustainable development[1] and carbon neutrality (the new frontier of community planning), as an integral part of their comprehensive plans.

Comprehensive plans establish broad goals in an effort to maintain a balance among the conflicting interests of the governing institutions, the citizenry and the landowners, and developers.

Establishment of Goals and Objectives

The goals statements themselves are usually general, and they set the parameters for the quality and "feel" for the future development of the jurisdiction. They are often criticized as being innocuous "motherhood and apple pie" type assertions. For example, in 1978, Anne Arundel County, Maryland, adopted a new comprehensive plan with three goals described as ". . . the foundation for this Plan." One of the goals, the overall social goal, was to: ". . . provide the best possible opportunities for all of the people to earn a living, to have a comfortable home, and to enjoy physical and emotional health, personal security and safety, access to new skills and knowledge, and control over their own lives" (Anne Arundel County, 1978). Certainly, the goal is important; however, it offers little in the way of advice for those making development decisions, either in the public or the private sector.

Today's comprehensive plans are moving past general awareness of community issues and turning these dreamy, "apple pie" assertions into statements of action. Throughout each section of a comprehensive plan the goals and objectives serve to support and strengthen the vision of the planners and community leadership for what has been termed *livable communities.*[2] Organizations such as the Center for Livable Communities, an offshoot of the Local Government Commission, have helped define the commonality of the new urban design and development trends (neotraditional planning, sustainable development, transit-oriented development, and the new urbanism) and provide concrete design and decision-making guidance for stakeholders, local governments, citizens, and the private-sector developers engaged in plan development and updates.

The first step in transforming or developing a plan that is active rather than passive (leaving design and development decisions open to widely varied interpretation) is to include focused, specific goals. They reflect strong attitudes about shortcomings or conflicts in prior comprehensive planning efforts or the rate of growth being experienced in the community. The Fairfax County, Virginia, Board of Supervisors in 1987 appointed 20 civic and business leaders to a countywide Goals Advisory Commission (GAC). The action was a response to a divisive conflict over the county's explosive growth and government efforts to control it. The panel spent 11 months in intense analysis and dialogue about county and industry past practices. In addition, three months of controversial public hearings were held by the GAC, the county's Planning Commission, and the Board of Supervisors. The resulting 18 goals formed the basis for a three-year, multiphased review of the county's comprehensive plan. In contrast to the Anne Arundel goal, a typical goal in the adopted Fairfax plan follows:

[1]The UN report *Our Common Future,* commonly referred to as the Brundtland Report, defines sustainable development as ". . . development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). This document is regarded as a catalyst of the global movement to approach development holistically, with attention to the interrelated issues of the environment, the economy, and social equity.

[2]*The Ahwahnee Principles: Toward More Livable Communities* (Calthorpe, et al., 1991) outlines planning strategies for both the local and the regional level that can help communities develop comprehensive plans that are action based and resource efficient. The overriding concept of livable communities is premised on reduced automobile reliance through sound neighborhood design that is pedestrian friendly, with services and businesses easily accessible to a large number of the residents, thus reducing the effect of sprawl.

> Transportation—Land use must be balanced with the supporting transportation infrastructure, including the regional network, and credibility must be established with the public and private sectors that the transportation program will be implemented. Fairfax County will encourage the development of accessible transportation systems designed, through advanced planning and technology, to move people and goods efficiently while minimizing environmental impact and community disruption. Regional and local efforts to achieve a balanced transportation system through the development of rapid rail, commuter rail, expanded bus service and the reduction of excessive reliance upon the automobile should be the keystone policy for future planning and facilities. Sidewalks and trails should be developed as alternative transportation facilities leading to mass transit, high density areas, public facilities, and employment areas" (Fairfax County, 1990).

It is important that all stakeholders be involved in the goal-setting process; although the focus of the plans may be led by the local governing body, the developer and the land development consultant can be seen as partners in this effort and not adversaries.

Once developed, the goal statements set a standard against which the actions of both the land developer and the local governing body are judged. In preparing the client's plans, the land development consultant must consider how those plans address these overriding goals. The team representative will likely be called upon to justify the proposal and must be sure the plan is characterized as a solution rather than an exacerbation of a problem identified in the plan.

Inventory and Trends

Inventory and trends analysis provides a starting point or snapshot of the community and its citizens' mind-set. The inventory is a valuable resource to the development team, as it includes a demographic analysis of the population of the community. It shows statistics such as age distribution, household formation, income, labor force, and home and automobile ownership. Along with a large-scale map showing existing land use, the plan describes land use characteristics, including a breakdown of number and type of housing units, structural condition, and land and building area of nonresidential uses. The plan also provides economic data, such as retail sales and manufacturing output. Many plans contain information on real estate absorption and conversion rates, property sales, and leasing activity, while others also offer statistics on commuting patterns and transportation use. With the help of the land development consultant, the developer uses the inventory to determine the needs of residents and business, and their financial capacities and limitations.

The premise of comprehensive planning is that by identifying growth patterns and adapting land use and economic controls, it is possible, if determined good public policy, to alter the patterns. The application of these controls may involve redistribution of public resources in accordance with reordered priorities. Strict controls and disincentives may be considered to prevent or deter specified development actions. Conversely, policies may be adopted that provide incentives to land developers and users that succeed in altering their actions to achieve the goals of the plan.

Incentives may simply take the form of public support for a desired change in zoning, or they may be financial in nature by providing density bonuses, low-interest loans, or tax credits to the developer. Policies that suggest bonuses or other financial incentives typically do so to encourage a particular form of development, in line with the plan, that results in additional public benefit (i.e., affordable housing, new public facilities, and/or enhanced resource protection) beyond the base level of performance. The plan may suggest that public funds be applied to critically needed public works improvement projects in areas where growth is desired. It may recommend the timing of development to keep pace with those improvements.

Land Use Maps

Accompanying the comprehensive plan text is the proposed land use map. Often color-coded or shaded, the generalized land use maps of the community represent a graphic depiction of the relationship of existing and future land uses and facilities. The map divides geographic areas into desired and projected uses and intensity. These areas usually represent the broad categories of land use, such as residential, commercial, industrial, and other employment centers. Subcategories of development intensity show the gradation of land use patterns. For instance, the map may show that a high-density residential area is a desirable future use adjacent to an existing commercial center. The map defines the boundaries of the area and provides a range of relative densities. The map frequently shows the proposed location of significant facilities, such as transit centers, proposed freeway interchanges, regional shopping malls, and schools. It offers a snapshot of what the community would like to be at a distant, but determined, point in time. Figure 7.2 provides an example of a comprehensive plan land use map.

The mapping of land use at large scale often generates considerable controversy. By its nature, a map provides geographic references and landmarks to which people can relate—the corner down the street, the area across from the shopping center. The generalized land use map, therefore, appears to fix geographic location for the information it presents. Consequently, it is not uncommon for residents to view the plan as a source of absolute information rather than a recommendation for future development.

Often, however, land development does not conform to the finite categories shown on the map. The plan map may propose that an existing residential neighborhood is redeveloped to a higher density or a major facility is shown in a location that concerns some people in the community. Citizens often lose sight of the fact that the plan serves only as a guide. So, too, the fact that the plan spans a 10- to 20-year

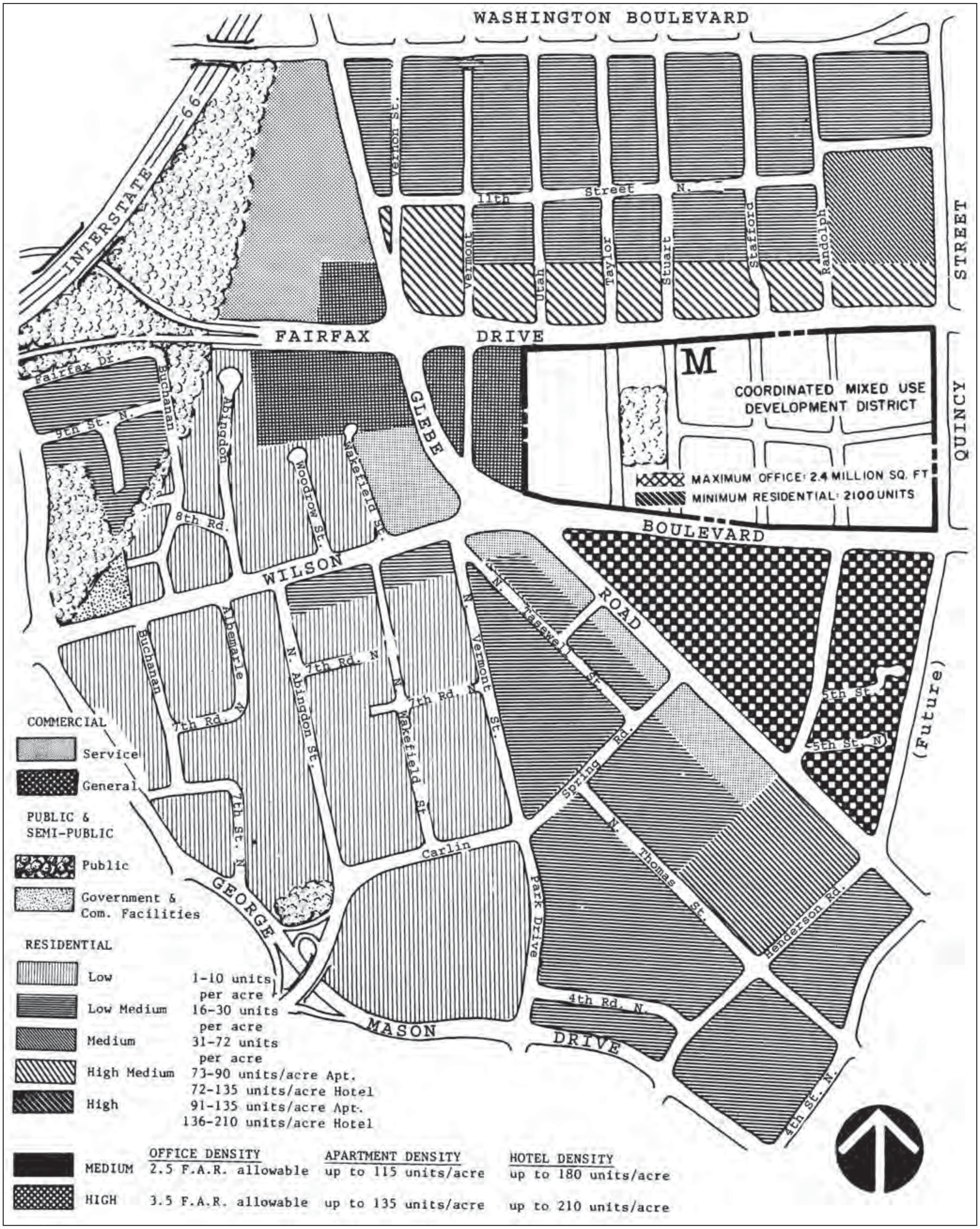

FIGURE 7.2 Example of a comprehensive plan map.

period is often forgotten. Some properties may undergo several use changes awaiting conditions favorable to the ultimate land use, and some, toward the end of the life of the plan, may wait for changes proposed by a new plan. Reference to the plan's designations for broad sections of the community ignores the fact that the plan, in some instances, intends for individual parcels to develop differently.

To eliminate some of the ambiguity created by scale and time, many communities undertake a multitiered and multiphased planning effort. This effort narrows its vision, often at several intermediate steps, in order to examine smaller subsections of the community. At its extreme, the plan makes parcel-by-parcel recommendations on land use, density, compatibility, and the facilities that serve them. When this happens, the comprehensive plan begins to resemble the zoning ordinance more than a plan to guide future development. However, even at this scale, the plan still serves only as a recommendation for future development, albeit a strong one.

Plan Implementation

Although the goals statements in the plan represent the community's vision of quality of life and future development, the plans for implementation are the key to that vision's realization. Despite its detail and breadth of coverage, the comprehensive plan is, in fact, only a guide in most jurisdictions. The governing body should, and in most cases does, strongly consider the plan's recommendations when making land use or fiscal decisions. However, it does not, in most jurisdictions, carry the force of legislative acts adopted by the jurisdiction, such as the zoning or subdivision ordinance. Despite this, the link between those ordinances and the plan is important, as most communities rely on the findings in the comprehensive plan when considering zoning and development applications. The zoning ordinance may mandate that the land developer consider the detailed provisions of the plan and address those issues in the development proposal. In a minority of states, sometimes referred to as *plan conformance jurisdictions,* the plan is a mandatory directive for land use regulations, and, by law, zoning decisions must conform to the plan's mandates. For purposes of the following discussion, the majority rule that the "plan is a guide" will be studied.

The existing zoning of a parcel takes precedence over the recommendations of the comprehensive plan in almost all cases. This is true even where the use and intensity provisions of the plan are more restrictive than those in the zoning ordinance. For this reason, an important role of the comprehensive plan is to recommend the adoption of changes to ordinances that regulate land use and development. The governing body of a jurisdiction may amend zoning and subdivision ordinances without specific direction from the comprehensive plan. However, the courts often find that such actions are an abuse of authority when they are accomplished without the rational basis offered by comprehensive planning analysis.

To the land development consultant, the comprehensive plan is more than just a guide to a community's future physical growth. Rather, the plan represents a historical depiction of the community and a retelling of the planning process that the community undertook to develop its vision. It represents an invaluable resource in the data and direction it offers, yet the language in the text, whether it relates to an overall policy or recommendation for the developer's parcel, is often vague. Frequently, the plan leads to varying interpretation by regulatory officials, citizens, or the developer. This adds to the considerable challenge facing the land development consultant and the developer in preparing the development proposal.

What to Look For and How to Use the Comprehensive Plan

Depending on the size of the community and its particular planning and zoning authority, the comprehensive plan might consist of one or several documents and maps. Many large localities will segment the land area into several planning areas or sectors. Where this occurs, the text provides extensive discussion of both jurisdiction- and sectorwide policies, issues, and opportunities.

Some communities identify smaller areas that warrant special study, such as business districts, industrial areas, transit centers, areas of important institutional use, or other significant concentrations of population and employment. Such areas often have unique circumstances deserving closer examination due to their presence in the community. Finally, there may be distinct functional plans that address partial elements of the plan that are of special importance to the community including transportation, sewer and water, the environment, urban design, and even trail systems. Prince George's County, Maryland, has several such plans: a Gateway Arts District Plan, a Transit Oriented Development Plan, and, most recently, a Green Infrastructure Plan that identifies important environmental features and environmental corridors. As is the case with the area plans, these also examine issues and opportunities and provide a set of policies considered in development review and budgeting. The plan specifies how the community intends to achieve its specific goals. These functional plan recommendations overlay and work in conjunction with the underlying plan and parcel-specific findings—see additional discussion under "Overlay Zones" in the "Zoning" section of this chapter.

All documents and maps that relate to jurisdiction-wide issues must be assembled by the land development team and analyzed for possible impact on a specific parcel planned for development. Table 7.1 presents the variety of plans produced in a given municipality.

The consultant must obtain the most recent version of the plan and keep it current. Local governments periodically revise their comprehensive plans, both in their entirety and on a piecemeal basis. Minor small-area amendments may have been adopted in response to new information or circumstances or by another developer's or citizen's proposal. The governing body frequently acts on these amendments

TABLE 7.1 Listing of Montgomery County General, Master, Sector, and Functional Plans

The type and number of plans available from various public agencies that can aid in the early design stages of a project vary widely according to the municipality. For example, this list describes the types of plans available for Montgomery County, Maryland.

General Plan:

Identifies, in broad terms, those areas suitable for various types of land uses—residential, commercial, agricultural, open space, etc.

Local Area Master Plan:

Are available for each of the county's 27 planning areas. The local area master plans include a statement of planning policies, goals, and objectives, and a description of the planning area. Plans also include maps outlining recommended land uses, zoning, transportation facilities, and recommended general locations for public facilities, and possibly even include recommendations for scheduling financial capital improvements.

Sector Plans:

Are comprehensive plans for a portion of the Master Plan area. They describe the relationship of various land uses to transportation, services, and amenities. Plans may include maps or other graphics, text, and design guidelines.

Functional Master Plan:

Shows details of a specific system such as major highways, drainage, and stormwater management systems.

apart from a more extensive plan review process; therefore, interim amendments will usually not appear in printed versions of the plan. The planning office or town clerk is required to maintain an index and file of plan amendments.

Comprehensive plans with a multiple-tier structure most often provide a parcel-by-parcel analysis. This analysis offers detailed use, intensity, and design recommendations that apply to the development of each parcel. The identification and evaluation of these recommendations, as they may affect a proposed development, are among the most important responsibilities of the land development consultant.

Jurisdiction-wide comprehensive plan maps and text usually limit their scope to broadly defined geographic areas and identify density or intensity ranges that apply within these areas. The more narrowly focused sector plan may attach a more specific range or absolute maximum density for a targeted area or parcel. Of particular importance are recommendations for project density or intensity, or other conditions required to achieve the full potential of a given site. The plan may include techniques to reduce potential impacts on the neighborhood and community as well as the environment.

The land development consultant must understand how the community prepares its land use maps and the intent of their graphic representations. For example, a symbol proposing a regional shopping center site on the comprehensive plan's generalized land use map may not necessarily fix its location. The text may refer to specific circumstances or conditions that are favorable to another site in the general area of the symbol. Furthermore, specific land use maps, within the area or sector plans, may make explicit recommendations for specific parcels.

Land uses different from those shown on the maps are often permitted and encouraged, depending on circumstances and conditions identified in the text. For example, the map might show a broad geographic area identified as low-density residential; however, text might explain that nonresidential uses, such as neighborhood shopping or service facilities, are appropriate. In such cases, the plan specifies conditions that the land developer must consider in developing such uses.

The land development consultant must review the discussion of available public facilities such as roads, water, and sewer. The existence of such facilities, system capacities, and timing of future improvements is important where these entities are needed to support the proposed development; in some communities, the adequacy and phasing of public facilities expansion controls development. For instance, Anne Arundel County, Maryland, adopts a sewer and water master plan as a functional element of its comprehensive plan. This master plan shows areas of existing service and planned expansion of service areas in 5-, 10-, and 20-year increments. Therefore, even when the comprehensive plan and actual parcel zoning agree on land use and density, the sewer and water master plan dictates lot size and project density. Consequently, the final project may be significantly less intense than envisioned, unless the developer can expand the system or defer the project to a consistent time frame with the adopted comprehensive plan. Policy language in the plan often prohibits the developer from constructing needed improvements to advance project development. Anne Arundel County uses this approach to discourage premature development in areas where growth is not anticipated or desired.

The land development consultant must identify the techniques and procedures that the local government uses to accomplish plan recommendations. These procedures may range from new or revised regulations or disincentives that discourage development to incentives that provide greater economic return to the developer in exchange for features that provide public benefit. The land development consultant must consider the fiscal impacts of these recommendations in determining project feasibility.

Because of the nature of the comprehensive plans as a guide, interpretation of the plan within which development is to occur is of utmost importance. Following the review of all pertinent ordinances and plans, the land development consultant would be wise to set up preliminary meetings with reviewers at the local level. These meetings are a necessary part of the process to reduce misunderstandings and identify areas of conflict or agreement between the goals of the client and the interpretation of the plan by the reviewing agency.

ZONING

Introduction

Despite the effort involved in adopting a comprehensive plan, legally, in most jurisdictions, it serves only as an advisory recommendation. In these majority jurisdictions, the plan does not have the force of law. That task falls to the community's zoning ordinance. The zoning ordinance is the legislative means by which a community sets detailed requirements for all aspects of the use of land. These requirements include use, layout, and intensity of each parcel of ground within the government's jurisdiction as well as height, setbacks, parking, open space, signage, and impervious area.

Although zoning is the primary means by which the comprehensive plan is implemented, ideally the plan's recommendations are the primary guide for making zoning decisions. While in majority jurisdictions a decision-making body may disregard the recommendations of the plan, it does so at the risk of losing regularity and uniformity in its zoning practices. In its simplest form, zoning separates different or incompatible land uses and serves as a nuisance-prohibiting device. Its purpose is to reduce the likelihood of one use creating a nuisance or having an undesirable impact on occupants or future occupants of adjoining property (i.e., it ensures compatible uses). For instance, operation of a business such as a grocery store requires the installation of signs, lighting, parking, and trash disposal facilities and generates traffic, from both customers and delivery trucks. If that grocery store operates next to a residence, the adjoining residents' use and enjoyment of their property is diminished. The traffic, noise, activity, and lighting are likely to become a nuisance that infringes on the residential character expected by the homeowner. Its location has become less desirable as a residence than others in the neighborhood. However, it may also have the simultaneous effect of increasing the value of the land on which the house is built by generating pressure to expand the commercial area and, thus, increase the value of the property. Conventional zoning seeks to prevent such conflicts by providing greater separation between incompatible uses. Where greater distance cannot be achieved between incompatible uses, the zoning ordinance requires other techniques to reduce impacts such as a different architectural solution, smaller signs, a larger yard between the building and property lines, fencing, landscaping, or restricted hours of operation.

The zoning ordinance achieves separation by defining categories of land use that relate to agricultural, residential, commercial, office, and industrial uses. The ordinance is usually organized in a hierarchy that reflects intensity and operating impacts on the community. Typically, the zoning categories are further broken down into zones or zoning districts. These represent the differing types and intensity of uses possible within the broad category. The regulations for each district specify what uses may or may not be constructed or undertaken on property within its boundaries. The most common zoning ordinances present an exhaustive list of land uses permitted in each zoning district. The zoning ordinance also regulates how much density and intensity of development is acceptable on property in each specific zone.

For instance, under the broad category of residential, an ordinance might specify districts for low-, medium-, and high-density development. Each zoning district would specify a maximum number of housing units allowed on each parcel of land. The text usually expresses this as a minimum lot size or number of dwelling units per acre. The ordinance may also list types of permitted residential development, such as single-family detached and single-family attached, and garden or high-rise apartments. In addition, the ordinance sets standards for the size and arrangement of structures on each lot or parcel. These might include the maximum area of lot coverage permitted for buildings and the setback of those buildings from adjoining roadways and property lines. Zoning ordinances regulate maximum building height, distance between buildings, required off-street parking, and similar features. The community adopts these standards as a protection to adjoining property owners who rely on the ordinance to anticipate potential conflict or impact on their own property. These standards become an essential element in the design of a project. Figure 7.3 is exemplary of the detailed control language found in a typical zoning ordinance.

RESIDENTIAL DISTRICT REGULATIONS 3-403

PART 4 3-400 R-4 RESIDENTIAL DISTRICT, FOUR DWELLING UNITS/ACRE

3-401 **Purpose and Intent**

The R-4 District is established to provide for single family detached dwellings at a density not to exceed four (4) dwelling units per acre; to allow other selected uses which are compatible with the residential character of the district; and otherwise to implement the stated purpose and intent of this Ordinance.

3-402 **Permitted Uses**

1. Accessory uses and home occupations as permitted by Article 10.
2. Dwellings, single family detached.
3. Public uses.

3-403 **Special Permit Uses**

For specific Group uses, regulations and standards, refer to Article 8.

1. Group 2 - Interment Uses.
2. Group 3 - Institutional Uses, limited to:
   - A. Churches, chapels, temples, synagogues and other such places of worship
   - B. Convents, monasteries, seminaries and nunneries
   - C. Family day care homes; child care centers and nursery schools which have an enrollment of less than 100 students daily
   - D. Group housekeeping units
   - E. Medical care facilities, limited to nursing facilities which have a capacity of less than fifty (50) beds
   - F. Private schools of general education which have an enrollment of less than 100 students daily
   - G. Private schools of special education which have an enrollment of less than 100 students daily
3. Group 4 - Community Uses.
4. Group 5 - Commercial Recreation Uses, limited to:
   - A. Commercial swimming pools, tennis courts and similar courts
5. Group 6 - Outdoor Recreation Uses, limited to:
   - A. Golf courses, commercial
6. Group 7 - Older Structures, limited to:
   - A. Antique shops

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   - B. Art and craft galleries
   - C. Rooming houses
   - D. Summer theatres
7. Group 8 - Temporary Uses.
8. Group 9 - Uses Requiring Special Regulation, limited to:
   - A. Home professional offices
   - B. Accessory dwelling units

3-404 **Special Exception Uses**

For specific Category uses, regulations and standards, refer to Article 9.

1. Category 1 - Light Public Utility Uses.
2. Category 3 - Quasi-Public Uses, limited to:
   - A. Colleges, universities
   - B. Conference centers and retreat houses, operated by a religious or nonprofit organization
   - C. Cultural centers, museums and similar facilities
   - D. Housing for the elderly
   - E. Institutions providing housing and general care for the indigent, orphans and the like
   - F. Medical care facilities, except nursing facilities which have a capacity of less than fifty (50) beds
   - G. Private clubs and public benefit associations
   - H. Quasi-public parks, playgrounds, athletic fields and related facilities
   - I. Child care centers and nursery schools which have an enrollment of 100 or more students daily
   - J. Private schools of general education which have an enrollment of 100 or more students daily
   - K. Private schools of special education which have an enrollment of 100 or more students daily
   - L. Alternate uses of public facilities
   - M. Dormitories, fraternity/sorority houses, rooming/boarding houses, or other residence halls
3. Category 4 - Transportation Facilities, limited to:
   - A. WMATA facilities

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RESIDENTIAL DISTRICT REGULATIONS 3-406

4. Category 5 - Commercial and Industrial Uses of Special Impact, limited to:
   - A. Commercial off-street parking in Metro Station areas as a temporary use
   - B. Convenience centers
   - C. Funeral chapels
   - D. Marinas, docks and boating facilities, commercial
   - E. Offices
   - F. Plant nurseries

3-405 **Use Limitations**

1. No sale of goods or products shall be permitted, except as accessory and incidental to a permitted, special permit or special exception use.
2. All uses shall comply with the performance standards set forth in Article 14.
3. Cluster subdivisions may be permitted in accordance with the provisions of Sect. 9-615.

3-406 **Lot Size Requirements**

1. Minimum district size for cluster subdivisions: 7 acres
2. Average lot area
   - A. Conventional subdivision lot: 8,800 sq. ft.
   - B. Cluster subdivision lot: No requirement
3. Minimum lot area
   - A. Conventional subdivision lot: 8,400 sq. ft.
   - B. Cluster subdivision lot: 6,000 sq. ft.
4. Minimum lot width
   - A. Conventional subdivision lot:
     - (1) Interior lot - 70 feet
     - (2) Corner lot - 95 feet
   - B. Cluster subdivision lot:
     - (1) Interior lot - No Requirement
     - (2) Corner lot - 70 feet

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5. The minimum district size requirement presented in Par. 1 above may be waived by the Board in accordance with the provisions of Sect. 9-610.

3-407 **Bulk Regulations**

1. Maximum building height
   - A. Single family dwellings: 35 feet
   - B. All other structures: 60 feet
2. Minimum yard requirements
   - A. Single family dwellings
     - (1) Conventional subdivision lot
       - (a) Front yard: 30 feet
       - (b) Side yard: 10 feet
       - (c) Rear yard: 25 feet
     - (2) Cluster subdivision lot
       - (a) Front yard: 20 feet
       - (b) Side yard: 8 feet
       - (c) Rear yard: 25 feet
   - B. All other structures
     - (1) Front yard: Controlled by a 35° angle of bulk plane, but not less than 25 feet
     - (2) Side yard: Controlled by a 30° angle of bulk plane, but not less than 10 feet
     - (3) Rear Yard: Controlled by a 30° angle of bulk plane, but not less than 25 feet
3. Maximum floor area ratio: 0.30 for uses other than residential

3-408 **Maximum Density**

Four (4) dwelling units per acre

3-409 **Open Space**

For subdivisions approved for cluster development, 15% of the gross area shall be open space

3-410 **Additional Regulations**

1. Refer to Article 2, General Regulations, for provisions which may qualify or supplement the regulations presented above.
2. Refer to Article 11 for off-street parking, loading and private street requirements.
3. Refer to Article 12 for regulations on signs.
4. Refer to Article 13 for landscaping and screening requirements.
5. Refer to Article 17 for uses and developments which require the submission of a site plan.

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FIGURE 7.3 Example of zoning district text.

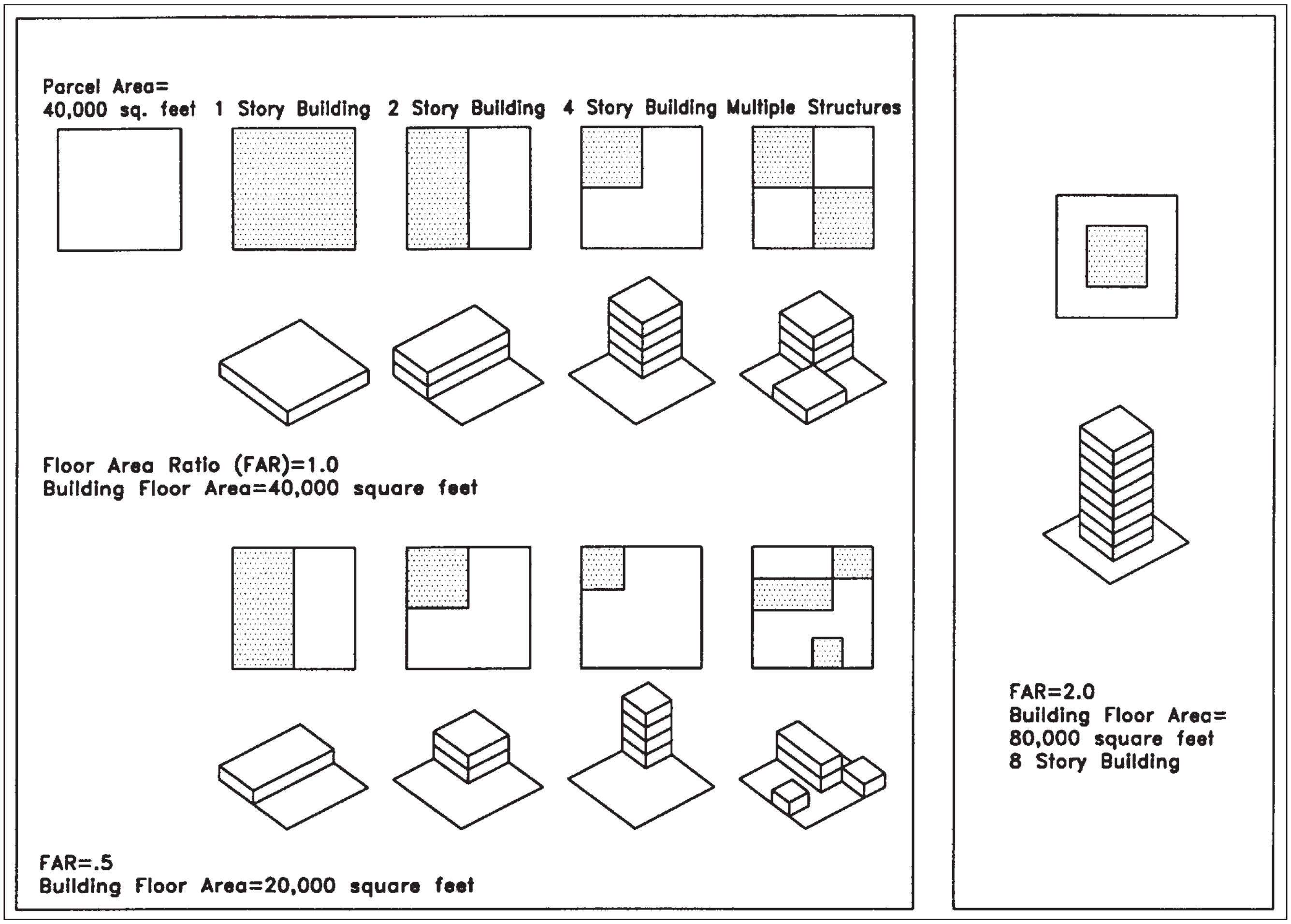


FIGURE 7.4 A graphic depiction of FAR.

The Zoning Map

Zoning does more than just prevent conflicts between land uses. Through the adoption of a detailed map (an example is shown in Figure 7.4), zoning is also used to achieve the land use patterns endorsed in the comprehensive plan. The map that accompanies the zoning ordinance text shows the division of the entire jurisdiction into the zoning districts defined in the text. These zoning districts reflect the actual zoning of the land. Applications to rezone property are routinely viewed in terms of the property or area-specific recommendations embodied in the approved comprehensive plan. Both the zoning ordinance and the zoning map are tools essential to the realization of the comprehensive plan's goals.

How local jurisdictions create their zoning maps varies. Many jurisdictions adopted the first zoning map simply as a graphic representation of land use patterns that existed at the time. Areas of vacant land were frequently zoned to a district similar to the surrounding area. In some communities, the adoption of the comprehensive plan is followed by a comprehensive, jurisdiction-wide rezoning. In such cases, the zoning map closely mirrors the land use patterns recommended in the comprehensive plan. In this way, the community encourages development to follow the comprehensive plan recommendations because a rezoning of the property is not required (see Chapter 9 for further discussion). The developer need only process project plans in accordance with other development controls, such as subdivision and building permit regulations. For jurisdictions that do not automatically rezone subsequent to plan adoption, rezoning may be required in conformance to the plan. Any more intense use requires that the developer seek a rezoning to a higher classification. Chapter 9 addresses rezoning and the map amendment process in more detail.

What to Look For and How to Use the Zoning Ordinance and Map

The zoning ordinance is usually a separately published title or chapter in the jurisdiction's code of laws. The land development consultant must be sure to use the most current version of the zoning ordinance. Many communities adopt text amendments on a continuing basis as the government responds to a variety of problems and constituents' issues. Most jurisdictions publish periodic text amendment updates, with a page-numbering system designed to ease insertion in a master document. These are sometimes available on a subscription basis. Others reprint the ordinance in its entirety only after the governing body adopts a substantial number of amendments. This requires that the land development consultant maintain a file of amendments until the reprint is available. With today's common usage of the Internet, many legislative bodies offer their amendments online at the jurisdiction's website.

The zoning map is often available in several forms and scales. A generalized zoning map is usually a single-sheet depiction of the community, perhaps at a scale of 1 inch = 2000 feet. The map shows major roadways, landmarks, and natural features, with zoning district boundaries identified by various symbols. Each district is labeled with the name of the zone that corresponds directly to the ordinance text. Frequently, the district name is a shorthand indication of the use and intensity of the district. While the meaning of these labels is consistent within a single jurisdiction, they often vary between jurisdictions. For instance, a district labeled "R-5" might be a residential district with a permitted density of five dwelling units per acre. It may mean a residential district permitting minimum lot sizes of 5000 square feet. On the other hand, it may simply be the fifth in a hierarchy residential district. Although this type of map is useful for understanding broad zoning and land use patterns in the community, it is less useful in verifying actual parcel zoning because the map in some jurisdictions omits property lines. In addition, zoning lines frequently bisect properties.

A large-scale map, often at 1 inch = 200 feet, may be maintained by the planning or zoning office, town clerk, or similar office of records. Maps at this scale frequently include parcel boundaries or they may reference a tax map designation for the property. In some jurisdictions, the official map shows additional information, such as previous and pending zoning and special exception or special permit applications, as well as subdivision activity.

Some jurisdictions use metes and bounds or other descriptions to maintain zoning district boundary records. It is the consultants' responsibility to compare these to actual parcel boundaries to verify property zoning. The client's best way to eliminate doubt, especially for the benefit of prospective lenders, is to have the appropriate government agency certify parcel zoning in writing. In some jurisdictions, a certification of zoning may become a legally binding decision unless appealed.

Some things to consider while preparing a feasibility study for a client are the jurisdiction's practice about the zoning of street and railroad rights-of-way, public and institutional properties, and major water bodies. These are some possible questions to ask: Are these areas zoned? Do zoning boundaries fall on centerlines or on property lines? This is important in calculating density for projects where right-of-way abandonment or surplus public property disposition is a factor.

The text associated with each zoning district usually describes the purpose of the zone. This determines the intended magnitude and character of the development, as well as the intended service or market area of nonresidential uses. In addition, the text provides a listing of land uses allowed in the district, which include:

- Uses permitted by right
- Uses permitted by right if certain specified conditions apply
- Uses permitted by special exception
- Uses permitted by special permit
- In some cases, uses prohibited in a specific zone

In undertaking a project where the use is allowed by right, the land developer need only show compliance with the requirements of the zoning ordinance. This usually applies whether the development is a single home, an entire residential subdivision, or a commercial facility. To secure approval from the jurisdiction, plan review is accomplished through the normal administrative procedures incorporated in the subdivision ordinance and building permit procedures. These ordinances are discussed later in this chapter.

When the intended use requires review as a special exception or special permit, approval authority usually rests with an elected or appointed body, or both. These are most frequently the jurisdiction's governing body, its planning commission, a zoning appeals board, or a zoning hearing officer. In addition to a review by the professional planning staff, the governing body usually holds public hearings to assess the attitudes of neighbors and civic groups toward the project. Using plans prepared by the land development consultant, the developer must justify the appropriateness of the proposed use. The approving authority may impose conditions to lessen potential impact, whether perceived or real. Following approval, the normal administrative procedures for subdivision and construction will apply.

The zoning ordinance provides details on the administrative and legislative approval procedures for uses requiring approval of a rezoning or special-exception application. These specify the required information needed for the preparation of plans and supporting documentation for rezoning and similar applications. Ordinance provisions also provide the methodology for amendments to the zoning ordinance text. Text amendments can change development potential as much as map amendments by, for example, allowing a use previously not permitted in a zone. Both amendment procedures may be initiated by either the governing body or the individual appellant. Chapter 9 describes these procedures in more detail.

Minimum or maximum standards cover virtually every detail in project design for each type of land use. Typical criteria identified in the zoning district text include lot size, density, lot coverage, and bulk requirements. These requirements strive to protect and preserve the character of the community by preventing overcrowding, reducing conflicts between neighbors and neighboring properties, guarding against encroachment on streets, and intrusion of traffic noise. Following are some examples:

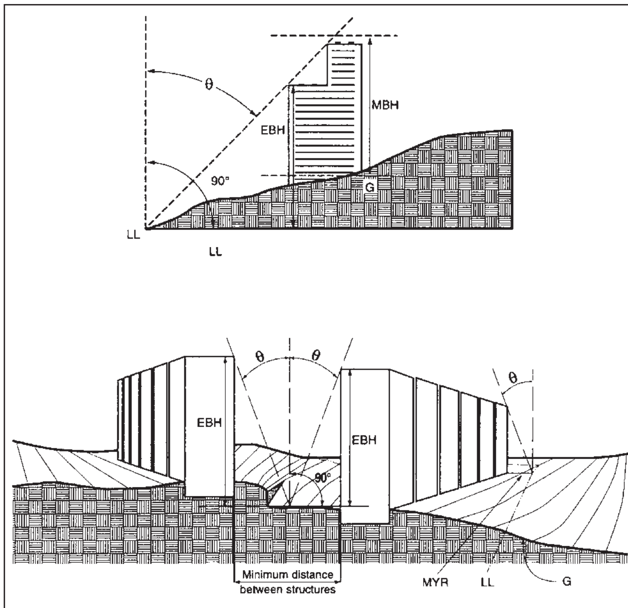
- Minimum and average lot size and lot width.
- Maximum density or intensity of development, usually expressed in dwelling units per acre for residential uses and floor area ratio (FAR) for nonresidential uses. Floor area ratio is the relationship of building area to parcel size. For example, on a 40,000-square-foot parcel, if the zoning ordinance allows a maximum FAR of 1.0, then it would be possible to construct a building or buildings totaling 40,000 square feet of floor area. This could result in a single-story building covering the entire parcel, a two-story building covering half the parcel, or some other configuration. Yard and height requirements affect the actual parcel layout. An FAR of 0.5 for this same parcel would allow 20,000 square feet of building area. See Figure 7.4 for illustration of FAR.
- Maximum lot coverage, either by buildings or by impervious surface, often expressed as a percentage.
- Minimum required open space, again as a percentage, referring to parcel area unencumbered by buildings or parking. Often pedestrian-oriented hardscape is considered open space, especially in urban areas.
- Minimum front, side, and rear yard requirements that define the building envelope. These refer to the distance of building setback from property lines, including street rights-of-way, utility corridors, transit lines (most commonly rail), waterfront, or other environmentally sensitive areas. In some communities with waterfront property, the yard facing the water is considered the front yard. The ordinance may specify when structures or architectural features, such as porches and steps, may extend beyond the setback line. The front setback line is also called the building restriction line (BRL).
- Minimum lot width at the building restriction line. If the lot is shaped so that its width at the normal setback line does not meet the minimum standard, the building restriction line is forced to be located farther from the front property line, to a point where the width complies with the standard.
- Maximum or average building height, in feet and/or stories.
- Angle of bulk plane or a similar representation of the relationship of building height to property line. This protects adjoining property views or access to sunlight and airflow. Figure 7.5 illustrates the angle of a bulk plane as applied to building restriction lines.
- Functional requirements or standards including off-street parking, landscaping, screening, buffering, and tree preservation.

Special-exception or special-permit uses also have minimum standards listed separately in the text that identify criteria for size and intensity, proximity to other properties or facilities, landscaping, screening, and similar conditions that mitigate impact to adjacent properties.

Zoning Administration

An important principle of zoning is that a property can be developed to any land use that is allowed by right in the given zoning district, provided that the development meets district standards and complies with other development policies and regulations. By-right uses are those that are explicitly permitted in each zoning district and are fundamental to the district's character. How those uses are determined differs, as does the subsequent process of development review by the jurisdiction. The land development practitioner must understand how the local government applies its ordinance. The variations dictate what land use options exist and how project design is undertaken and affects the way in which local government approves development projects and the durability of that approval.

Special Exceptions. A special exception is a specific use permissible within a zoning district subject to the fulfillment of specific requirements dealing with compatibility and site-specific design. A special exception is one that generates additional impacts to the surrounding neighborhood and



Key	
θ	Angle of bulk plane
LL	Lot line
MYR	Minimum yard requirement
EBH	Effective building height
MBH	Maximum building height
G	Grade (finished)

FIGURE 7.5 Graphic showing setback and building restriction lines and angle of bulk plane.

warrants special consideration: For instance, churches, synagogues, or other places of worship are often considered a special-exception use in residentially zoned districts. Despite the potential for negative impacts, the principle underlying the classification of special-exception uses is that, if properly regulated, they are acceptable uses in the zoning districts where they are permitted. They are uses that adhere to the character intended by the zoning district, as well as the comprehensive plan. They may be desirable to the community and add to its convenience; however, due to possible impacts such as noise, traffic, or visual disruption, most zoning ordinances establish conditions that apply in the development of special-exception uses. Such conditions may include a limitation on the hours of operation, landscaping, buffers and barriers that exceed the standard specified for the underlying zoning district, and a specification of the activities permitted in conjunction with a special-exception use. The authority empowered to grant rezoning approval is usually the same one that grants special-exception approval as well; this may be the governing body, a planning commission, or a zoning hearing officer. These bodies hold public hearings to solicit input from community residents on upcoming cases that are in for consideration. (See Chapter 9 for more detail.)

In contrast to uses allowed by right, most ordinances specify that uses needing special-exception approval must comply with the community's comprehensive plan. These requirements subject development proposals needing a special exception to the broad variety of policies and restrictions in the comprehensive plan that might not otherwise apply. These could include density controls, requirements for specific environmental measures, constraints on traffic generation, or desirable public improvements. Frequently, these apply even to existing land uses proposed for redevelopment or expansion of long-established uses. Some jurisdictions administer a separate special-permit process. Projects that involve uses listed as needing a special permit must go through an approval process not unlike the special exception. However, the governing body frequently delegates its authority to a board of appeals or zoning staff administrator. Approval of a special permit comes with conditions attached that, like a special exception, help to reduce incompatibility between the use and adjoining neighborhood. Typically, opportunities for public hearings are incorporated into the process, allowing affected neighbors to voice support or opposition to the issuance of the permit.

Variances and Variations. Two processes that allow deviation from the zoning ordinance are variances and variations. A variance to zoning ordinance requirements may be granted by the governing body, a subordinate body to which that power has been delegated, or, in some jurisdictions, a quasi-judicial body appointed by judicial officials. As with other zoning applications, opportunities for public comment are normally provided. Most variance applications address building setbacks or similar technical requirements of the ordinance, due primarily to physical characteristics of the site under development, although some districts do allow usage variances as well. These usually occur in expanding or reconstructing existing land uses, where changes to the zoning ordinance make it difficult to adhere strictly to the current ordinance. In some instances, complying with newly adopted ordinances imposes a hardship on the property owner, who is otherwise unable to use the property in the manner permitted prior to the change in the zoning ordinance. The hardship must be peculiar to the property, and the variance must be necessary to allow reasonable use of the land. A purely economic hardship does not normally satisfy this hardship test. The approving authority may impose conditions on development. In granting the variance, it must ensure that the variance will not change the basic character of the area, weaken enforcement of the ordinance, or provide precedent for future requests for variances. As with variances, variations must not provide precedent for future requests; however, in the case of variations, "practical difficulties" may be a consideration in the review of the application. In general, the findings must conclude:

1. The granting of the variation will not be detrimental to the public safety, health, or welfare, or be injurious to other property.

2. The conditions on which the variation is based are unique to the property for which the vatiation is sought and are not applicable generally to other properties.

3. The variation does not constitute a violation of any other applicable law, ordinance, or regulation.

4. Because of the particular physical surroundings, shape, or topography of the specific property involved, a particular hardship to the owner would result as distinguished from a mere inconvenience, if the strict letter of these regulations is carried out.

Additionally, nonconformity may exist as to a lot, use, or structure that does not fully comply with the requirements of the zoning district in which it is located. This situation often occurs with the adoption of a new zoning ordinance, text, or map amendment after a subdivision plat is recorded, or when a land use is legally established. In most instances, the goal of the community and the governing body is to eliminate nonconforming uses and/or structures. Where that is not practical, most ordinances also include provisions that explain the conditions under which such uses may continue to operate or expand (i.e., certifying the nonconforming uses).

There are two types of nonconformities: nonconforming as to standards and nonconforming as to use. The first case addresses uses permitted in a district whose development standards have since been revised in the ordinance. This frequently occurs in older residential areas or established commercial areas when the lot size, density, parking, or setback requirements have been changed in the zoning ordinance.

Most ordinances usually allow these uses to continue, provided they are not expanded or enlarged, but require that future additions comply with the new requirements. For instance, a new garage added to a house would have to comply with new setback provisions, unless a variance is granted. A developer constructing a new department store addition to an existing strip shopping center might be required to adhere to the newer off-street parking requirements. In a zoning district requiring lot sizes of 1 acre, the zoning ordinance will usually allow a house to be built on a smaller existing lot of record; however, the structure must otherwise fulfill all other requirements of the ordinance.

Sometimes, the actual use of a property becomes nonconforming due to a zoning text amendment eliminating the once-permitted use. Typical ordinance provisions allow the use to remain, but prohibit any expansion or enlargement. Repairs and limited reconstruction are allowed, although most require a nonconforming use to be terminated if a substantial portion—greater than 50 percent—is destroyed by fire or other casualty. Some communities also adopt a schedule to enforce the removal and/or amortization of nonconforming uses that they consider undesirable, such as billboards or mobile homes.

Zoning Concepts

Zoning ordinances fall into two general classes, although many communities' ordinances have evolved into a hybrid. Among these two types of zoning ordinances, there are several important distinctions in ordinance structure and administration. Conventional zoning, prescriptive, or Euclidian[3] zoning ordinances set rigid parameters. These prescribe very specific land uses and building configurations that are permitted on a parcel of ground and the standards applied to development.

Though the name may vary among jurisdictions, the concept of performance zoning incorporates flexibility into land use control. This type of zoning addresses more directly the impacts of the final development and use of a parcel, based on its unique physical and environmental characteristics. Rather than imposing strict standards, such an ordinance requires that the developer meet specific standards of performance. These standards often relate to stormwater runoff, industrial pollution or noise, traffic, population, or other factors important to the community. Like Euclidian zoning, a performance zoning ordinance usually specifies use and intensity. However, with performance zones, the land developer has greater latitude in determining the detailed requirements, such as lot size, building arrangement, and architectural treatment. To secure project approval, the developer must show how the proposed project meets the performance standards.

[3]Named after the landmark 1926 Supreme Court decision in the case of the *Village of Euclid, Ohio vs. Ambler Realty Company,* 272 U.S. 365 (1926), which established zoning as a valid exercise of police powers to protect public health, safety, and welfare.

Conventional Euclidian Zoning. The advantage of this type of zoning is greater certainty in both end product and project approval; however, the end result might be rather uniform developments. This is particularly true in residential uses, where large developments commonly have a cookie-cutter appearance. This approach to zoning does not allow the flexibility that a developer needs to address environmental concerns in site development. Nor can the developer respond to shifting market activity or preferences. In addition, the number of zoning categories and individual zoning districts is greatly increased with Euclidian zoning.

Performance Zoning. This type of zoning provides flexibility and often succeeds in attracting more variety and innovative projects. Greater protection of environmental resources and open-space areas can be achieved through the performance zoning process. Its disadvantage, however, is that it may result in greater expense in up-front analysis and less certainty for both the community and the developer. To community residents, it sometimes does not provide the desired clarity and certainty with respect to expected development. It is in performance zoning where greater conflicts may arise in the interpretation and establishment of requirements for development with differing views of development from the public and private sectors.

Form-Based Zoning. Although prescriptive in nature, form-based zones, unlike conventional zones, are not based on land use segregation; they regulate development through specific standards dealing with the relationships of building massing, proximity to streets, height, scale, and other elements that help define the character of a community. Regulations and standards in form-based codes are represented in both diagrams and words and are coded to a regulating plan that defines the intentions of a community within a regulated area.

Cumulative Zoning. Variations of this type of zoning might be the most common. As the density and land use intensity increases in the zoning district hierarchy, the range of permitted uses expands. Thus, a more intense district will permit all uses listed within that district, plus all uses in districts of lower hierarchy. One of the shortcomings of cumulative zoning is that the community may not attain the desired separation of uses and may suffer the resultant impacts caused by lack of separation. In a commercial district, for instance, it could be possible to construct single-family residences.

While separation is one of the basic intentions of zoning, economic and market forces usually work to discourage significant disparity in use. The principle of highest and best use generally works to discourage development to a use with lower economic return. Full development potential is the most widespread indicator of land prices. In addition, marketability of the lesser use declines if users perceive the proximate higher use to be incompatible or an undesirable neighbor. Although, in some respects, the mix of uses permitted by this type of zoning may be beneficial, since the extreme separation of residences from employment or services has, in large part, been responsible for the rapid growth in suburban sprawl and increased dependence on the automobile. This dependence has worsened roadway congestion by forcing more traffic onto major roadways. Those communities that recognize this respond by establishing mixed-use districts that encourage a variety of compatible uses. Strong government controls usually accompany the development of mixed-use districts. However, even as some jurisdictions attempt to encourage mixed use, many local governments now try to narrow the range of permitted uses in each district. The rationale for this position is the need for greater certainty in planning for the community's infrastructure.

Transitional Zoning. Many communities draw zoning district boundaries in a step-down fashion. This pattern seeks to provide gradation between two disparate uses, usually residential and commercial or office. In one approach, the community creates zoning districts of intermediate intensity between the incompatible classifications. This reduces the most significant conflicts between the more extreme uses. Figure 7.6 represents a zoning map with property divided into several districts between the most intense commercial zones and the least dense residential zones. The permitted intensity of commercial use reduces in each of several districts as distance from the most intense commercial area increases. Similarly, residential density may also increase for properties in districts located closest to commercial areas.

Some jurisdictions establish districts that provide for flexibility as well as a mix of uses and appearance where zoning classifications meet. These transition zones serve as buffers against the intense use. For example, townhouse-style offices may be required on commercially zoned property adjacent to residential areas. This encourages architectural compatibility in both scale and configuration with the existing residential community. The ordinance may also provide for changes in housing type; that is, town houses or garden apartments may be allowed as part of the transition. In either case, the text of the zoning ordinance often imposes landscaping and screening requirements as additional protection for the lower-density/intensity uses.

Transect Zoning. Similar to transitional zoning and first developed by Andres Duany and his firm DPZ, transect zoning[4] relies on a categorization system that organizes all elements of the urban environment on a scale from rural to urban. Its potential lies in (1) education (it is easy to understand), (2) coding (it can be directly translated into zoning categories), and (3) creating "immersive environments." An immersive environment is one where all the elements of the human environment work together to create something that is greater than the sum of the parts.

The transect has six zones, moving from rural to urban (see Figure 7.7). It begins with two that are entirely rural in character: rural preserve (protected areas in perpetuity) and rural reserve (areas of high environmental or scenic quality that are not currently preserved, but perhaps should be). At the urban end of the spectrum are two zones that are primarily mixed use: center (this can be a small neighborhood center or a larger town center, the latter serving more than one neighborhood) and core (serving the region—typically a central business district). Core is the most urban zone.

Between the extremes are two transition zones: the edge, which encompasses the most rural part of the neighborhood, and the countryside just beyond. The edge consists primarily of single-family homes. Although the edge is the most purely residential zone, it can include some mixed use, such as civic buildings (schools are particularly appropriate for the edge). Next is general, the largest zone in most neighborhoods. General is primarily residential, but more urban in character (somewhat higher density with a mix of housing types and a slightly greater mix of uses allowed).

Floating Zones

Many ordinances describe zoning districts that are unmapped but become fixed in the process of rezoning. These zones have a special purpose, and most usually respond to a specific comprehensive plan recommendation. Floating zones may provide transition between uses, as previously described, or they may address problems in geographic areas that have unique opportunities or constraints, such as an environmental resource or commercial or transportation center. Planned unit development is a typical type of floating zone, although communities apply it in varying ways.

Planned Unit Development (PUD) and Comprehensive Design Zones. This development form attempts to enhance both flexibility and functional relationships between land uses. With conventional zoning patterns, the land developer cannot easily respond to the changing market demand associated with shifts in the economy of the region. Nor can the developer address consumer preferences for other than a single lot size or housing type. Individual projects, undertaken in a small geographic area, by different developers sometimes lack cohesiveness, causing community identity to suffer. In addition, the extreme separation of land uses, which results from conventional zoning, often places unnecessary stress on community facilities.

The planned unit development—a mix of land use, building type, and intensity—can be constructed within a single project. It is most often applied in larger tracts of land by a single land developer. Typically, a PUD can include single-family detached housing, single-family attached housing, multifamily housing, and light neighborhood serving commercial retail uses. In larger projects, local zoning regulations may permit other, more intense uses.

Planned unit development allows the land development consultant the opportunity to consider design in a comprehensive manner, rather than treating each use individually and separately. PUD also presents design opportunities to address broad functional relationships between land use and

[4]Transect Applied to Regional Plans. *New Urban News.* September 2000. http://www.newurbannews.com/, accessed November 2007.

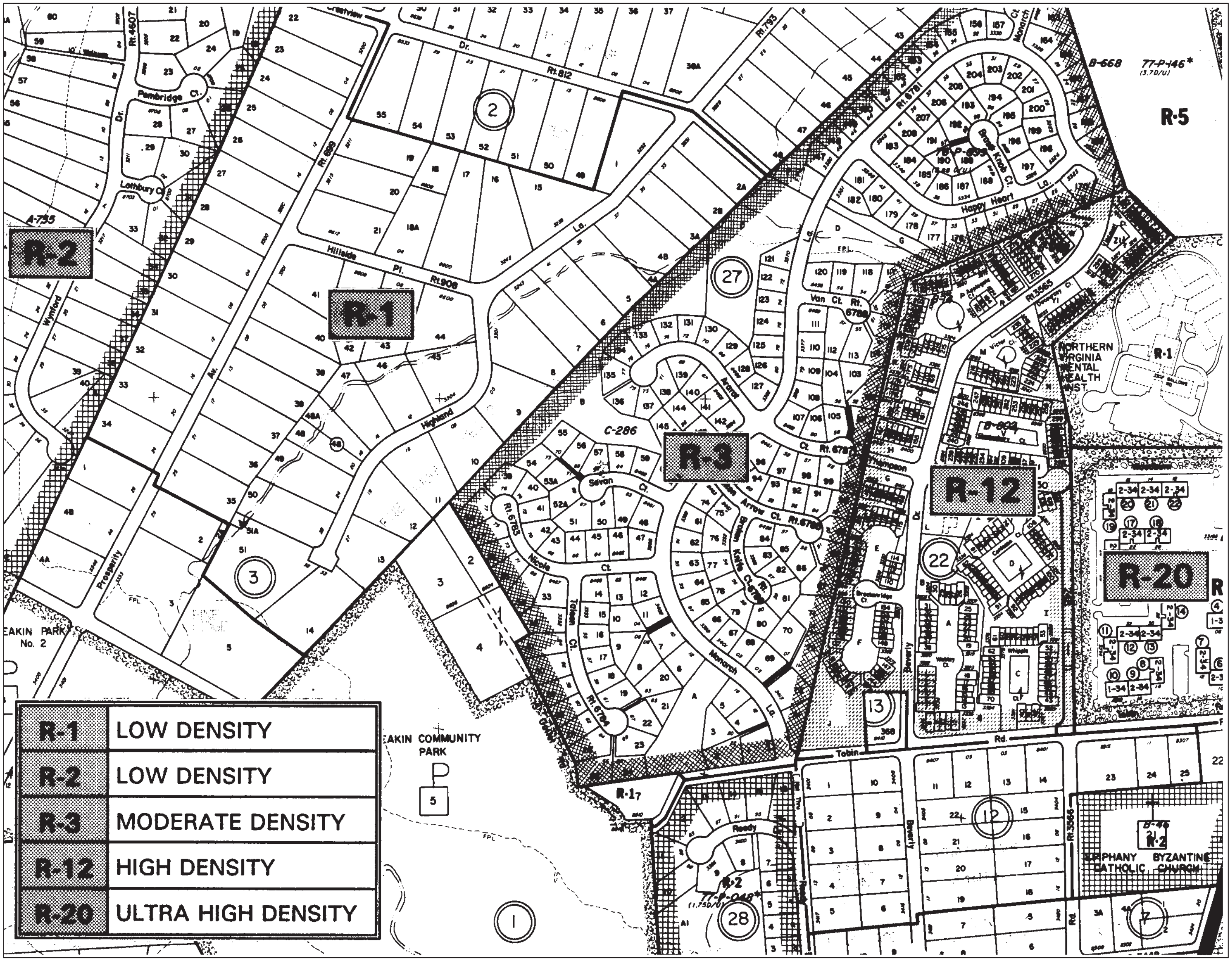


Figure 7.6 Zoning map showing zoning transition.

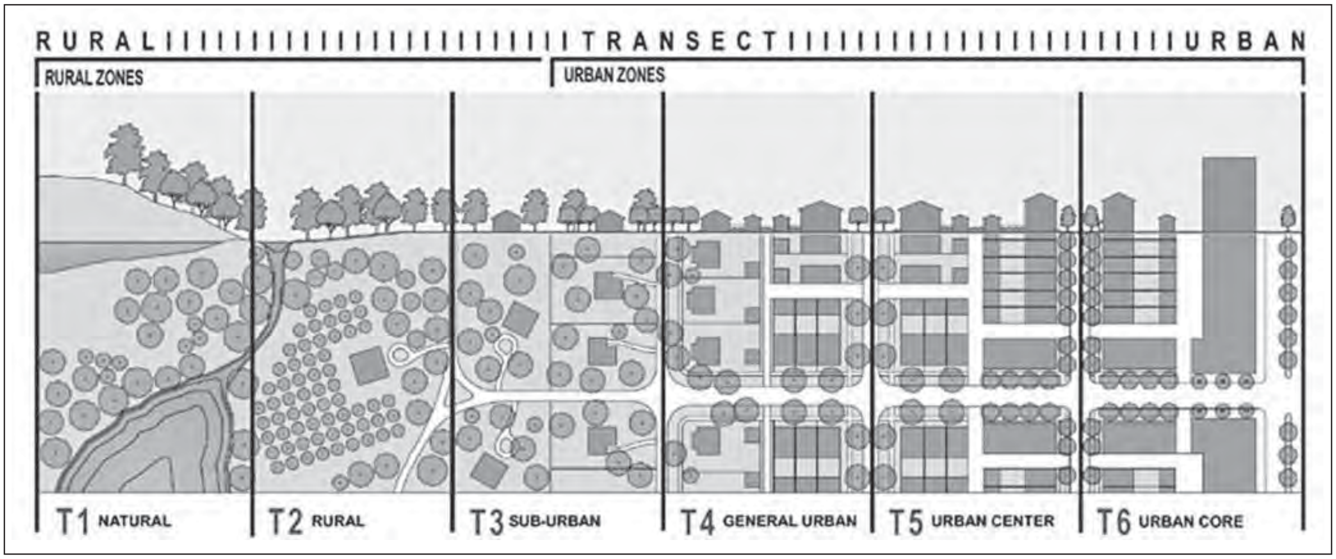


Figure 7.7 Illustration of the transect system. (Courtesy Duany Plater-Zyberk & Company)

facilities. These include entrances to the community, vehicular and pedestrian traffic, stormwater management, and other infrastructure systems. The land development consultant has greater control over placement of uses, their design, and access between them. In-depth discussion on these issues is found in Chapter 11.

Uses in a PUD interrelate in a common and controlled setting, providing more flexibility than can be achieved in conventional zones. The consultant addresses elements that affect community appearance and identity with a unified approach including architectural style, landscaping, street furniture, open space, and signage. This comprehensive approach to design and construction of PUDs allows for a more efficient use of the land. In addition to a greater efficiency in the use of the land, the developer is in greater control of product marketing and the business environment. As a result of this design flexibility, cost savings in street and utilities design, construction, and maintenance may benefit both the developer and public agencies. Planned unit development and comprehensive design planning processes are more intense for the developer and the planning professional, demanding much more up-front work, more community outreach, and a longer time frame; the trade-off is increased flexibility and, often, increased density or intensity of development.

Some communities delineate PUD districts on their zoning maps. Ordinance provisions set use and intensity conditions that reflect the district's relationship to other uses. Other communities have the zone "float," and it becomes fixed during the rezoning process, frequently where the applicant has assembled several properties and the project may take on the general characteristics of the underlying zones. A PUD in an otherwise residential area may still be required to incorporate primarily residential uses. However, housing type and arrangement may deviate from conventional district requirements. Often, limited neighborhood serving retail areas are also allowed. Planned unit development provisions may also address areas intended to be primarily shopping centers and industrial and office parks. Some jurisdictions allow PUD as a special exception, which most closely resembles the floating zone, with the processing and administration differing among jurisdictions.

The flexibility associated with PUD often means that the final development may be viewed as less predictable by the community. Consequently, PUD approvals often involve extensive review procedures that might discourage their application. Considerable up-front design costs may be encountered by the developer, with no guarantee of project approval. Frequently, PUD provisions also require the developer to provide additional on-site amenities, such as open space, recreational facilities, and land for public facilities such as schools or fire stations.

Many jurisdictions recognize the benefits of PUD to the community. Zoning ordinances often provide land developers with incentives to assemble smaller parcels of land into larger tracts. These incentives come in the form of higher densities, relaxation in lot size requirements, more intense uses, and increased flexibility in design.

Cluster and Conservation Zoning. Cluster is an alternative planning arrangement for residential developments, particularly in greenfield suburban and rural settings, although the premise could be applied to any site regardless of location. Cluster regulations frequently allow smaller lots in exchange for more community open space and a more pleasing community setting. At the same time, cluster can provide greater public benefit, such as preservation of sensitive environmental features. Cluster has also been successfully applied to save historical sites and productive farmland. Conservation zoning is an extension of the cluster concept, where the open space or historic use is placed in a perpetual conservation easement or trust.

Cluster differs from PUD in that it typically is a change in neither land use nor housing type. If the underlying zoning district specifies single-family detached residences, town houses or apartments usually cannot be built. It is merely a reconfiguration of the technical lot size and setback standards that apply in subdivision design. The density specified in the zoning ordinance is unchanged. Communities that allow cluster development by right set specific standards that are applied in subdivision or other administrative ordinances. This gives the development team the flexibility to design a plan that can accommodate unique site conditions or address market desires. As a result of the design flexibility, the developer can realize construction cost savings through reduced infrastructure quantities, and the community can gain valuable open space.

Despite the inherent advantages of this zoning, especially when applied properly in context to a site, some communities that once allowed cluster by right now require either rezoning or special-exception approval for cluster development. Where this change has been made, local legislators have acted in response to citizens' fears that the smaller lots somehow diminish adjoining property values. Others are concerned that cluster may allow the developer to create more lots than otherwise possible, despite the overriding control of zoning district density. The delay and exposure, in terms of both time and money, associated with these processes often serve to discourage land developers from using cluster development, despite its benefits. The development team must balance these competing demands. Chapter 11 describes cluster development design in detail, including a graphic comparison of the differences between the traditional and cluster zoning.

Mixed-Use Zones. With the reemergence of traditional neighborhood design (TND) and smart growth, mixed-use zones have become more widely used. These require that a development contain a mix of uses, such as residential and commercial retail or office. Some mixed-use zones establish a procedure by which master or sector plans land use recommendations are implemented. Different communities and municipalities create mixed-use zones to serve various development purposes; more urban areas might have mixed-use infill zones to allow flexibility and encourage innovation in planning and design in areas where most properties are developed. Others might create mixed-use town center zones to provide incentives for development in older, established mixed-use centers, benefiting the community by reinvestment and the developer by using existing infrastructure. Mixed-use zones tend to provide flexibility in development standards.

Regardless of the focus of each mixed-use zone, the overriding principle behind them and the purpose for their creation is to support the vision of livable communities. By providing a mix of compatible/complementary uses, mixed-use areas strive to create a vibrant, 24-hour environment; cultivate a distinct community identity; minimize vehicular traffic; preserve environmentally sensitive areas; utilize, improve, or upgrade existing infrastructure; and effectively create a safer (in terms of security and overall environmental health) livable community.

Overlay Zones. Communities sometimes use overlay zones to address areas with special problems; unique opportunities resulting from local culture, historic land use, or location; or unusual physical characteristics. In addition to the conventional district boundaries, overlay zones are either mapped or described in the ordinance text. Typical situations that suggest the use of overlay controls include airports, historic areas, highway corridors, and floodplains. The development must conform to both sets of zoning district criteria, or the more restrictive if conflicts are apparent. Figure 7.8 provides a graphic representation of a typical overlay map. Overlay zones may include transit-oriented developments in close proximity to major transportation routes or mass transit facilities; arts districts are also increasingly common designations created to help develop areas' identities and provide a focal point for a particular community.

Transferable Development Rights (TDRs). Historic, agricultural, and other unique natural resource areas are often prime development sites. Most communities place a high priority on the protection of these properties and often attempt to discourage their development. Consequently, owners of these properties cannot realize the value of these properties if development should be prohibited. Therefore, some communities have adopted a system that enables the transfer of development potential elsewhere in the community, while leaving the property itself undisturbed. These development rights are usually sold to developers of property elsewhere in the jurisdiction, allowing the original landowner to keep the underlying property and profit from its value. Transferable development rights are a major tool available to communities to help manage growth by directing it to appropriate areas while addressing other community goals such as focusing financial resources for public facility improvements in more developed areas, where they can efficiently serve the population. It should be noted that TDRs involve a land regulatory process outside the scope of traditional zoning enabling acts. Therefore, special legislative authority is normally required to legitimize TDR regimes.

Once TDRs have been approved, the community typically defines "sending" and "receiving" areas within the comprehensive plan. Sending areas are those areas to be preserved. Underlying zoning or a similar indicator determines the development potential of the property; the landowner is allowed to sell that potential to a user in a receiving area. Selling the development rights of a property prevents the sending property from undergoing future development while yielding an economic benefit to both parties in the transaction.

Developers who acquire TDRs may increase project intensity accordingly. Maximum densities and other condi-

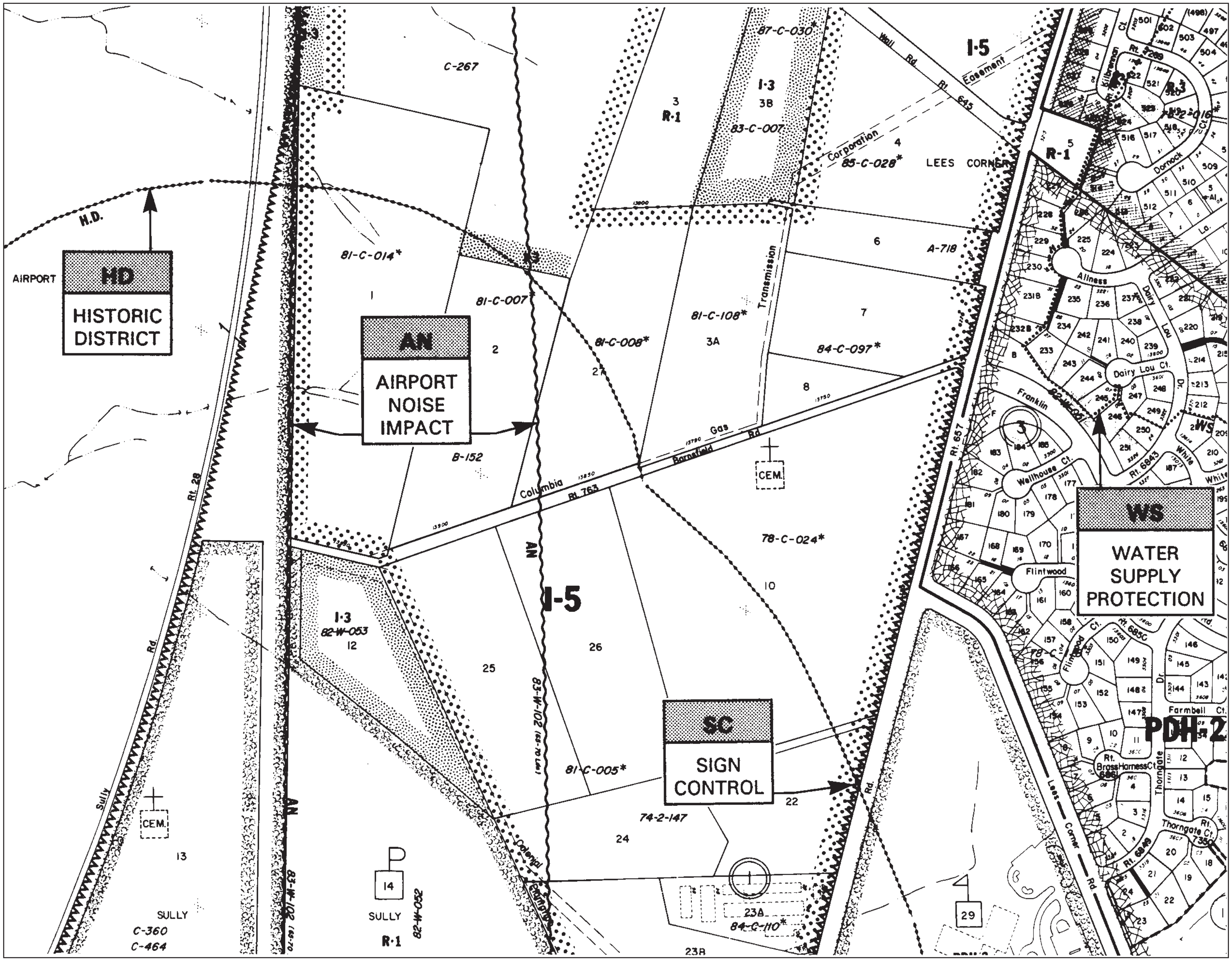


Figure 7.8 Example of an overlay zone on a map.

tions established in both the comprehensive plan and the zoning ordinance—designations such as TDR 2 or TDR 4, where the number indicates the additional number of units per acre that might be achieved through the TDR process—regulate development of the receiving property. This type of zoning most closely resembles the floating zone. Additional development rights need not be purchased, but new criteria apply when they are. Development conditions in the community's ordinance protect property owners near the receiving area, who may face greater impacts and higher densities than anticipated.

As environmental issues and safeguarding of sensitive environmental lands continue to increase in priority in many jurisdictions, variations of the traditional TDR legislation have emerged, including trading of impervious areas and even house size within similar designated sending and receiving areas. Transferable development rights are another tool that savvy planners, developers, and legislators are utilizing in an attempt to find innovative ways to foster environmentally responsible growth in the appropriate locations and appropriate manner.

Exclusionary Zoning. This type of zoning specifically prohibits a particular use in a district that might otherwise permit it. This prevents a use that might have extreme impact, such as noise, odor, or pollution. However, the more familiar use of the term is a negative connotation that applies to ordinances that limit housing choices to the upper end of the housing market and may include such tactics as restricting small lot zoning, requiring minimum house sizes, prohibiting mobile homes, or excluding apartments. Such ordinances indirectly discriminate against low- and moderate-income groups, and, as such, exclusionary zoning is becoming the subject of court challenges. Coupled with high land prices and development costs, exclusionary ordinances also work to restrict a community's labor force by limiting housing opportunities for office and service workers, who often fall in the low- to moderate-income category. The situation is exacerbated when these displaced or remotely located workers must commute greater distances, thus spending a disproportionate amount of money on transportation and adding to the burden on regional transportation systems.

Inclusionary Zoning. In contrast to exclusionary zoning, inclusionary zoning attempts to expand access for households of low and moderate income. This is accomplished by adopting provisions that encourage developers to provide housing and facilities in affordable price ranges, often in exchange for other development benefits the jurisdiction is capable of permitting. The simplest way to achieve this is to amend the zoning ordinance to allow greater variety of housing opportunities other than single-family homes on large lots. However, because of other factors that affect housing cost, this is not necessarily effective in and of itself.

One approach that is gaining in popularity is the adoption of "affordable dwelling unit" ordinances. These require the developer to provide for a certain number of controlled-price dwellings in exchange for a density bonus. The additional density compensates the developer for the added construction cost of the affordable units. To implement such an ordinance, the community must modify zoning district design requirements to accommodate the increased number and type of units that may be constructed on the site. These changes most frequently include lot size, setbacks, and maximum building coverage and housing type. Take the example of a 100-acre site that is zoned to permit a density of four dwelling units per acre. If a 20 percent density bonus is granted, it may not be physically possible or desirable to build 480 single-family detached homes on the property. By modifying the ordinance to allow a percentage of the units to be built as townhouses, a more attractive project may be possible, still allowing the developer to earn a profit, while accommodating the affordable units.

Increase in housing costs has priced many service people, teachers, police, and firefighters, out of the housing market. To create additional opportunities for them, some jurisdictions are providing "workforce housing" in a similar manner as moderately priced housing was provided through affordable housing ordinances. In workforce housing, a certain percentage of the housing units may be set aside for purchase at a reduced rate or at reduced loan rates. As with affordable housing, incentives are provided to the developer in the form of higher densities.

ZONING CHANGES

Chapter 9 of this book discusses the actual rezoning process, the purpose for the rezoning, and the preparation of plans as required by governing bodies to demonstrate the rationale for change. This section discusses the effect of zoning change.

The rezoning application often represents what the developer intends to construct on the subject property. The plans and drawings show, conceptually, how the project will look once built. If the governing body approves the rezoning, future development of the property is controlled by the new district regulations.

Although the property owner or developer who obtained the property's rezoning is bound to the new zoning, and perhaps to the conceptual drawings presented to make a case for the change, there may be no obligation to develop the property as shown in the rezoning application. Consider the example of a commercial zoning district that permits both an automobile service station and a lumberyard. The developer may already have a service station operator as a client, to whom he intends to sell the property once it is rezoned. During the rezoning process, the developer may have successfully demonstrated that the service station was both appropriate and needed in the community. The land development consultant prepared the client's plans, showing how the final product would look once completed. After the zoning is approved, the client of the developer may build the service station, but backs out of the project for economic reasons. In view of the fact that the zoning district allows a variety of uses by right, the developer is free to establish any of the land uses that the district permits. He or she may sell the property to another developer, who finds that construction of a lumberyard may be more appropriate. This flexibility enables the developer to respond to changing market conditions. However, community residents may find the lumberyard incompatible with their community, leading to further commercialization of the neighborhood.

In another situation, the comprehensive plan may recommend that an area zoned for low-density residential use is more appropriate as a multifamily project. However, the increased density creates the need for new roadways to serve the community, funding for which the local government cannot afford. Residents of the jurisdiction become frustrated when the rezoning is approved, because traffic congestion is worsened by new projects in the area. These scenarios have led many communities to seek the adoption of state enabling legislation to create several hybrids of zoning categories with special restrictions and to impose adequate public facility ordinances in later stages of the development process.

These new or hybrid categories are characterized by the granting of rezoning to districts of higher density or more intense use in exchange for greater certainty and an increase in the number of amenities or facilities that serve the public health, safety, and welfare. These typically involve extensive negotiation between the developer, the governing body, and, in some instances, the citizens of the community.

These types of ordinances, and the rezonings granted under their provisions, are occasionally the subject of court challenges on constitutional grounds. Citizens sometimes believe that the governing body has bargained away too much, and developers are concerned that they have been unfairly treated. Therefore, a local land use attorney frequently takes a lead role on the land development team. However, the land development consultant should become familiar with the administration of local ordinances, past practices, and existing case law.

In states that allow conditional zoning, the governing body has the power to grant a rezoning if the developer agrees to meet certain conditions. Most often, the local government imposes or allows the developer to voluntarily offer these conditions to reduce the impacts of the proposed use or existing uses and future public facilities. Conditions can improve compatibility between adjoining uses or reduce the project's demand on support facilities and infrastructure. The developer is compensated for the extra cost of these conditions by the higher economic returns expected from a project of greater intensity or density. Critics of conditional zoning suggest that it may be abused by the governmental agency to obtain numerous concessions while exceeding reasonable expectations of the developer.

Proffered Zoning

Used extensively in the urbanizing portions of Virginia, proffered zoning is similar to conditional zoning but mandates that the development conditions be volunteered in writing by the developer prior to action on the rezoning request. The significant difference is that the developer *proffers* (pro offering) to bind development of the property to a specific development plan or set of textual conditions. In addition, the developer sometimes offers to construct improvements to public and private facilities that minimize impacts generated by the development. The developer may also provide operational and aesthetic incentives to the community as a condition of rezoning approval. The final plan and proffers are usually the result of extensive negotiation with community residents and the governing body (see Chapter 10 for additional information).

The proffered conditions must be in writing, must be signed, must relate to the rezoning itself, and must be in accord with the comprehensive plan. If the governing body accepts the proffers and approves the rezoning, the proffered conditions then run with the land. Thus, both current and future owners or developers are bound to the approved plan and conditions agreed to during proffer negotiations. Any change to the development plan or the actual proffers must be accomplished through a subsequent rezoning.

Contract Zoning

Unlike conditional zoning, which binds only the landowner, this zoning methodology binds both the landowner and the governing body to agree on conditions in exchange for certain zoning concessions. Some courts have ruled this type of zoning invalid, arguing that the governing body does not have the power to bargain away its police powers. This form of rezoning can result in spot zoning to accommodate private interests and is often challenged as being capricious and arbitrary.

RELATED TECHNIQUES IN DEVELOPMENT REGULATION

Adequate Public Facilities (APF) Ordinances

As noted earlier, some communities have found that rapid growth has outstripped their ability or commitment to provide the public infrastructure needed to support development. One technique used to address this problem is the adoption of an adequate public facilities ordinance. Such an ordinance requires that the developer defer a project if the projected demand on public services exceeds the total capacity or funding approval of any of the systems. The typical systems covered by an adequate facilities ordinance include transportation, water, sewer, and school systems. More recently in some communities, fire and police availability and response times have been included in the APF ordinances, as fire and police service and effectiveness can be seen as directly tied to the quality and effectiveness of the infrastructure systems. As with the TDRs process, adequate public facilities regulations involve a land regulatory process outside the scope of traditional zoning enabling acts. Consequently, special legislative authority is normally required to legitimize adequate public facilities ordinances.

Implementing such an ordinance first requires that the governing body conduct studies to determine the total capacity of public systems. This is derived by adding to the capacity available in existing systems those facility improvements that are planned, budgeted, or funded within a specified period. Most ordinances use the time span covered by the community's capital improvements project budget, typically four to six years. For some systems, capacity can be determined by direct measurement, such as by measuring design capacity for sewage or water treatment. For others, a policy must be established concerning level of service before the calculation of projected use is made. For instance, the governing body must determine the number of students per classroom that is acceptable to the community before determining total capacity of the school system. Similarly, in determining the capacity of the transportation system consider the level of service and congestion that will be tolerated by the community.

The jurisdiction must then determine the existing use of those systems, again either by direct measurement or estimated usage. In estimating current demand, the jurisdiction might determine the average use generated by each residence and equivalent nonresidential operation. It is possible to calculate per-unit demand by analyzing historical data, field research, and demographic information such as housing type or number of bedrooms.

The community must also estimate the projected demand for projects that are committed but not completed. These are projects that are approved but not built or projects over which the government has no control because a discretionary approval, such as rezoning, is not required. These are called projects "in the pipeline."

The final step is determining available capacity and system adequacy. If, after subtracting current and committed demand from the total system capacity, capacity remains, then the facility is considered adequate. However, each development proposal must demonstrate that its demand on systems will not exceed that available capacity. Again, this is done by determining per-unit demand, such as average gallons per day of water use, or number of vehicle trips per day of traffic generation.

In communities with an adequate public facilities ordinance, a project cannot be approved if its demand will exceed the available capacity. In some cases, however, the developer is allowed to finance improvements that increase system capacity, thus allowing the project to meet the adequacy test or pay into a fund to be used by the jurisdiction to make the improvements necessary to meet the public facility needs; this method is known in some cases as "pay and go." Another option available to the land development team is the implementation of measures that reduce the demand generated by the project. An example of this is the creation of a shuttle system to transport residences to a mass transit station, thereby reducing the number of vehicle miles traveled that a new residential project would generate; in this case, special binding documents are prepared and recorded.

Development Review Point Systems

A criticism often lodged against zoning is that it is too inflexible. As noted earlier, zoning often does not allow sufficient leeway for the developer to adjust to unique site conditions, changing economic/demographic conditions, or consumer preference. In response, a number of communities have initiated comprehensive development review systems that rate projects according to the success or failure with which they address certain criteria. Fort Collins and Breckenridge, Colorado, are among those jurisdictions that have enacted this type of ordinance.

The criteria to judge development applications in these communities focuses on compatibility, design, and demand on public facilities and environmental impact. The jurisdiction attaches discrete weighting factors to each of the criteria, based on their relative importance to the community. Each project is then given points based on its success in addressing the issues identified. Those that achieve a minimum threshold of points will be approved for development.

Deed Restrictions and Covenants

Government regulations are not the sole means of controlling land use and development. Private controls imposed by the landowner, developer, or subsequent lot purchasers are also an effective way to establish and enforce desired development patterns. Deed restrictions and covenants are typical private controls. These are agreements between individuals that create self-imposed restrictions on design, use, and alteration. Enforcement is pursued without intervention from the jurisdiction, usually through civil court suit by the parties to the agreement.

The most common examples of restrictions and covenants are the homeowner and condominium association agreements that a developer creates as part of a development project. The agreements often place limits on what purchasers may do with their property as a way of maintaining aesthetic controls. When homeowners take title to their property, they also assume certain obligations to consider the rights of others in the community. The restrictions may limit the size of structural additions and control paint colors, landscaping, and other features to ensure that individual actions are in keeping with the character of the community. These agreements may be more stringent than, and often supersede, government zoning regulations.

During the initial stages of project occupancy, it may be the developer who enforces the restrictions. While project sales are under way, maintaining the appearance and character of the project is essential. After project buildout, however, it falls to the residents of the community, who are parties to the agreement, to enforce the restrictions. Design review committees are appointed by many homeowners' associations to control the activities of individual homeowners in a development.

Developers often use similar covenants as part of an overall marketing plan in projects where the developer is not the builder. When portions of the development are sold to a number of different builders, agreements control the actions of builders within a large project. These often address architectural style, amenities, and housing price range. The covenants frequently control builders' activities during construction, as well as the operation of builders' on-site model homes and sales offices.

In a commercial development, restrictions may be imposed on signage, operating hours, or similar activities. Covenants take on importance in a commercial venture because of the potential impact of one business on another. The success of a retail center depends heavily on tenant mix, and operations and covenants are an important means of ensuring that the character of a retail center is maintained. In addition, the developer may have been required to establish them as a condition of the government's rezoning or subdivision approval. Again, these are privately enforced, although the government may play a role if conditions of approval are violated.

Covenants are established in two ways. They are often indicated on the final subdivision plat that is recorded in the jurisdiction's land records. If the covenants are extensive, a plat reference will indicate where in the land records the covenants are located. They form a private contract agreement that applies to all the lots in the subdivision, and any purchaser of the land automatically becomes party to the contract. The covenants have an important role in community design and appearance. Consequently, the land development consultant should assist in drafting them. In order to ensure that the covenants are legally binding and in conformance with the state's real estate laws, an attorney must review and conduct final drafting of the documents prior to recordation.

A second way of establishing covenants is through the action of individual landowners, who can place restrictions within deeds of conveyance. Groups of landowners can also act together and attach restrictions to their lots, usually for their mutual benefit. These covenants are also recorded in the land records of the jurisdiction. It should be noted that a limited number of jurisdictions in the country have chosen not to adopt zoning ordinances. In the early 1990s a zoning ordinance in Houston, Texas, was defeated in a referendum and consequently remains as perhaps the largest American city without a zoning ordinance. In such areas, deed restrictions and covenants regulate land use and development. While the city relies on covenants and deed restrictions to regulate land use, it also exercises covenant enforcement powers.

Environmental Regulations

Protection of the environment has been in the public eye for many years; from seminal works such as Rachel Carson's *Silent Spring* (1962), highlighting the effects of pesticides on the environment and wildlife, to the first Earth Day in April of 1970, and more recently the production of Al Gore's movie and book *An Inconvenient Truth* (2006), a new wake-up call on the effects of global warming on the natural as well as the built environment has begun to resonate with design professionals, government agencies, and citizens. Localities have modified their ordinances and added new ordinances and regulations to help reduce the effects of global warming by encouraging change within the built environment. Forest Conservation regulations that require mitigation for loss of woodland and regulations that require mitigation for the loss of wetland areas are two factors that have had substantial impact on the development process. In many jurisdictions, environmental regulations are an integral part of the development process. The preparation and formal submission of environmental inventories that document existing conditions and identify environmental problems in need of remediation is increasingly common. While a natural resource inventory should be part of the development process of every project, rarely has it been a jurisdictional requirement until recently.

The green building movement has created a whole new industry. Cities as large as Chicago are going green (Davidson, 2002)—developing green roof demonstration projects and implementing ordinances and special economic incentives (Tax Increment Finance districts) that encourage public-private partnerships. Education programs on the value of building green for builders and developers that show financial savings and benefits of new technologies along with incentives from municipalities are spurring the development of green buildings and the expansion of urban open spaces. Other jurisdictions, such as Montgomery County, Maryland, and Arlington County, Virginia, are developing regulations to make green building certification a requirement for proposed developments. Although relatively new, the green building movement is spreading rapidly and causing new legislation to be written to incorporate its priorities.

As part of the green legislation being examined and implemented by governing bodies, some are considering issues closely related to global warming, such as reduction of carbon emissions through thoughtful planning and site selection, and through new technologies as they come into the marketplace.

Green Building and LEED Certification. Green building regulations are an outgrowth of the need to safeguard the environment and encourage stewardship of the land and natural resources. Several organizations have become key in the development of guidelines for green building and development; the U.S. Green Building Council (USGBC), a nonprofit organization based in Washington, D.C., made up of a coalition of building industry leaders, and the Natural Resources Defense Council (NRDC) are two of the more prominent and influential leaders in this endeavor. One of the many tools that exists to facilitate development in an environmentally sensitive manner, and the one more jurisdictions are implementing as a benchmark and effective measuring tool, is the USGBC's Leadership in Energy and Environmental Design (LEED) certification process.

As discussed in several of the other chapters, the LEED certification program consists of a set of rating systems for design and development of residential, commercial, industrial, and institutional uses, be they public or private. Each rating system has an accompanying checklist to help the owner/developer track design efforts against credit requirements for certification at various levels—Certified, Silver, Gold, and Platinum. Credits are accrued in various categories that range from the selection and development of a site to the quality, composition, and resource consumption of the building itself.

Green building standards have been around now for a few years primarily in a voluntary environment, but they are now being legislated. It is important for the land development consultant to be familiar with all aspects of the existing and proposed standards to help the client develop a project from the beginning with green guidelines as an integral consideration of the development and thus help to prepare for possible requirements that will result from the review process.

As the market responds to economics, receiving financial incentives and the added benefit of a reduction in operating and development costs will persuade developers to make their projects more sustainable and reduce any adverse impacts on the environment and surrounding communities. Decisions made at the onset of a project—such as site selection, development density, and community connectivity—are planning and design considerations that, when made in an informed and integrated manner with program development, can help achieve desired certification levels within project budgets and time frames.

SMART GROWTH

Introduction

Since the end of World War II, land use patterns have encouraged low-density developments, where the American Dream of owning a home could be realized. However, a partial result of capturing the American Dream has been an abandonment of our major cities by the middle and upper-middle class and the resultant ". . . racial and economical segregation, disinvestment in urban cores, environmental damage, and inaccessible housing, employment, transportation, and services."[5]

Further, because of a rapidly increasing population over the past four decades and the continuing expansion of the suburban rings around major metropolitan areas, communities throughout the nation are debating methods and laws to address suburban sprawl. The issue of how to address suburban sprawl has been on scores of ballots in cities and states across the nation during the past decade. As a result of this concern with suburban sprawl, local, state, and federal growth management groups have focused on the concept of *smart growth*. The smart growth movement evolved from statewide growth management initiatives and drew its name from legislation and programs developed by the State of Maryland, including its 1997 Smart Growth Areas Act (Godschalk, 2000).

Depending on one's views about growth patterns and particular social, economic, and interests in them, the term *smart growth* has a wide range of definitions and interpretations for what is and how it should be implemented. According to Anthony Downs, in the April 2001 issue of *Planning*, those debating the essence and implementation of smart growth fall into four basic groups: (1) anti- or slow-growth advocates and environmentalists, (2) pro-growth advocates, (3) inner-city advocates, and (4) better-growth advocates. Although these four groups are diverse in their interests and goals and certainly do not agree on many of the elements of smart growth, ". . . there is always cause for optimism. Even with different goals, the different groups may be able to reach a middle ground, especially if they keep in mind that each region of the country has unique needs and wide choices" (Downs, 2001).

The smart growth debate has intensified during the late 1990s and into the new millennium. "Last November there were no fewer than 240 anti-sprawl ballot initiatives around the country, most of them passed. Some stripped local authorities of the power to approve new subdivisions without voter assent. Others okayed tax money to buy open land before the developers get it (Lacayo, 1999).

Fundamentals and Principles

Smart Growth principles, according to the National Association of Home Builders (NAHB), include meeting the nation's housing needs, providing a wide range of housing choices, offering a comprehensive process for planning growth, and both planning and funding infrastructure costs. Other interest groups place more emphasis on protecting the environment, preserving open space, redeveloping inner core areas, and encouraging new forms of urban design that create and/or restore a sense of community. The range of principles is wide and varied; however, the common thread is to provide the housing need for the increasing population, while at the same time protecting the environment and enhancing the quality of life for all. "The goal of Smart Growth is not no growth or even slow growth. Rather, the goal is sensible growth that balances our need for jobs and economic development with our desire to save our natural environment."[6] This view of smart growth allows for the convergence of varying interests, supporting the balance of preserving the environment with the rights of landowners to develop their properties with more compact, higher-density/intensity uses.

The literature on smart growth presents a wide variety of issues, statistics, and legal analysis and suggests methods for implementing smart growth principles. Each interest group

[5]Connecting Neighborhood and Region for Smarter Growth, National Neighborhood Coalition, April 2000.

[6]Governor Parris Glendening of Maryland, remarks at the Partners for Smart Growth Conference, December 1997.

has its own set of priorities in terms of the issues of most importance and methods by which the principles of smart growth should best be implemented. David O'Neill, of the Urban Land Institute (ULI), suggests that although there is not a universal definition, there are the following smart growth features with common characteristics (O'Neill, 1999):

- Development is economically viable and preserves open space and natural resources.
- Land use planning is comprehensive, integrated, and regional.
- Public, private, and nonprofit sectors collaborate on growth and development issues to achieve mutually beneficial outcomes.
- Certainty and predictability are inherent to the development process.
- Infrastructure is maintained and enhanced to serve existing and new residents.
- Redevelopment of infill housing, brownfield sites, and obsolete building is actively pursued.
- Urban centers and neighborhoods are integral components of a healthy regional economy.
- Compact suburban development is integrated into commercial areas; new town centers, and/or near existing or planned transportation facilities.
- Development on the urban fringe integrates a mix of land uses, preserves open space, is fiscally responsible, and provides transportation option.

Smart growth respects both the rights of private property owners and the value of open spaces and natural resource lands. Open spaces are important components of communities. They provide recreational opportunities, habitat for wildlife, buffers for pollution, and places for people to gather and enhance their sense of place. Smart growth seeks to preserve these open spaces in the context of achieving a vision for a community's desired growth and development.

Open-space preservation is an essential community value and, therefore, a critical element of any smart growth initiative. The development of transferable development rights legislation along with agricultural preserve areas outside metropolitan districts is an indication of how municipalities are taking smart growth principles into account as they develop new statutes to deal with development and growth.

While environmental protection objectives traditionally have been viewed as conflicting with economic goals, smart growth seeks to identify those areas where both environmental and economic objectives can be achieved simultaneously. In many respects, as smart growth demonstrates, open-space protection complements economic development objectives.

The implementation of smart growth policies is as varied as the social, economic, and political environment of a given jurisdiction. There is no "one size fits all" solution, nor do all or the majority of smart growth principles need to be implemented to be successful in achieving the goals of smart growth.

There are countless opportunities and challenges inherent in the implementation of smart growth. Change is never easy, and it is certainly even more difficult when it involves perceived or real issues of property rights and fundamental changes in how future development is to take place. The implementation of smart growth policies influences the way we do business at all levels of government, and the results will not be seen for years to come.

In the years since its inception, and as regulations for it have been implemented, smart growth has received mixed reviews. Areas of the country that were spearheading the principle of smart growth have seen the trend reversed—including Maryland and the City of Portland, Oregon. Anthony Flint, a former reporter with the *Boston Globe* and an advocate for measured growth, believes that while development pressures will continue to propagate the sprawl patterns of past generations, the high cost to individuals living in outlying areas (becoming rapidly more apparent) will increase the demand for developments that are closer to the workplace and for walkable communities. High transportation and energy costs will quickly reduce the initial savings of lower housing costs further from cities. He believes that inclusionary zoning and affordability requirements can help make livable urban neighborhoods as prevalent as sprawl (Flint, 2006).

CONCLUSION

Much ground has been covered by this chapter, from defining comprehensive planning—what it is, how it is used, and what elements are taken into account when comprehensive plans are prepared—to types of zoning categories and uses, related procedures for regulating development, and, finally, a discussion of new development techniques that as part of the initial due diligence process, result in gains to the client as well as the community.

As the effects of global warming become apparent and the limits of our natural resources are underscored by water shortages and high energy costs, it is imperative that the land development professional become well versed in sustainable development techniques that will create not only more environmentally friendly developments but also the livable communities that we all strive to be a part of, whether we are designing, building, or living in them. Green building techniques combined with smart growth are a starting point; economic incentives and public-sector support for those developments that help fulfill the vision of a vibrant, sustainable community can get us a step closer to attaining those development goals.

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CHAPTER 8

SUBDIVISION ORDINANCES, SITE PLAN REGULATIONS, AND BUILDING CODES

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INTRODUCTION

With few exceptions, the development of land normally involves the subdivision or consolidation of property, site plan preparation and processing, and issuance of a building permit. The subdivision of land, as defined by most local ordinances, is the division of land into two or more parcels, whether for immediate or for future use. Additionally, contrary to the implication of the term *subdivision,* these same ordinances also cover the consolidation and/or reorganization of parcels into larger areas. Many jurisdictions also include condominium and cooperative ownership as forms of division where both horizontal and vertical division may take place. In these cases both the land and the building may be subdivided. Long-term leaseholds are frequently included in the definition as well.

Local governing bodies impose standards and procedures for the subdivision of land with the adoption of subdivision ordinances. Like the zoning ordinance, subdivision ordinances are an exercise of the local government's police powers. They are intended to protect the health, safety, and welfare of its citizens and facilitate community growth in a controlled manner. Subdivision ordinances are an important mechanism to ensure that proposed development complies with the requirements of the zoning ordinance. In addition, the ordinances provide protection to purchasers and users by ensuring that subdivided lots are suitable for their intended purpose.

Similarly, local governments retain a vested interest in knowing that its residents and business operators are provided with safe, durable, and efficient developments. Land is an exhaustible resource and its development is a primary generator of revenues needed to provide public services and maintain fiscal health. Government, therefore, assumes an important role in protecting that resource and demands that development projects remain marketable and a continued community asset.

In some jurisdictions, the conveyance of an unsubdivided portion of a master tract is a criminal violation. Therefore, pre-subdivision conveyances, leases, and establishment of condominium or cooperative regimes should be avoided.

Provided a proposed land use is permitted by right in the zoning ordinance and subdivision or consolidation does not occur, no specific approval may be required for development beyond building permit issuance. Building permits address the construction requirements for a single building on a single lot or parcel.

Together, site plans and building codes play an important role in ensuring proper review of proposed development projects and ensuring the safety and structural integrity of proposed buildings. In many jurisdictions, site plans are synonymous with subdivision plans and require only administrative review. In contrast, some jurisdictions require site plans to undergo greater scrutiny of not only an administrative staff review, but also the governing body, with public hearings as part of a very formal approval process.

The review processes for building codes and building plans have been established nationwide to ensure the health, safety, and welfare of future occupants of a structure. There are a number of nationwide building codes that are routinely used as the foundation for local jurisdictions to augment, in order to meet and reflect local concerns and issues.

The underlying purposes of land use ordinances discussed in this chapter are to protect the community at large from negative impacts of a forthcoming development and to ensure that time-tested standards are honored in the construction of new structures.

SUBDIVISION ORDINANCES

Evolution of Subdivision Ordinances

Subdivision of land has occurred for centuries in the United States. One of the shortcomings of early land subdivision and transfers was the accurate and consistent conveyance of information at the time of purchase or sale. To help minimize ownership disputes and create an accurate chain of division, plats were often created in addition to written deeds, which relied on metes-and-bounds descriptions. Metes-and-bounds legal descriptions were acceptable for large tracts of land in rural areas where concentrations of development had not yet occurred. In areas of concentrated development where multiple lots, streets, alleys, easements, and open space were already established, metes-and-bounds legal descriptions on their own were insufficient to establish clean and accurate chains of ownership and subdivision.

Early subdivision of land was largely a function of accepted surveying methodology, as was the case in early colonial cities such as Philadelphia. In 1785 the Federal Land Ordinance was passed by Congress as a means of generating income for the federal government. The Federal Land Ordinance called for the survey and platting of land ceded after the Revolutionary War, and west of the Appalachian mountains, into 36-mile-square townships. Each township was to be further subdivided into 1-square-mile (640-acre) areas, and sold in whole or in part to early settlers and land speculators. This ordinance largely established the foundation for today's land subdivision. (See Figure 8.1.)

Until 1928, when the Department of Commerce created the Standard City Planning Enabling Act (SCPEA), subdivision ordinances were largely an exercise in the coordination of plats and legal descriptions. The SCPEA granted local municipalities the right to regulate the subdivision of land and "provide for the proper arrangement of streets in relation to other existing or planned streets and to the master plan, for adequate and convenient open spaces for traffic, utilities, access of fire fighting apparatus, recreation, light and air, and for the avoidance of congestion of population, including minimum width and area of lots" (Department of Commerce, 1928). Items such as grading, utility construction, and bonding were also established as a part of the act and were permitted to be conditions precedent for subdivision plat approval. It is important to note the difference between zoning and subdivision ordinances: whereas zoning ordinances regulate the permitted use of the land and the spatial relationships of those uses, subdivision ordinances specify the policies, procedures, and standards by which the infrastructure systems necessary to support the use are physically created. Additionally, subdivision ordinances have been in place much longer than zoning requirements.

As the population of urban centers moved to city fringes and farther out to create suburbs, subdivision ordinances were increasingly used as a means of growth control. Municipalities recognized that uses permitted by zoning could be further guided with effective and well-thought-out subdivision ordinances. As a condition of plat approval, municipalities used these ordinances to affect street patterns, clustering of housing, placement of public infrastructure, and open space. As subdivision ordinances evolved, approvals for land subdivision included exaction requirements and, finally, the addition of impact fees. Starting in the 1990s and increasingly today, subdivision approvals are tied to adequate public facilities requirements for schools, water, sewer, and police and fire protection. Finally, the latest addition to many subdivision requirements is the allocation of perpetual easements that set aside natural resource areas for public benefit. (See Figure 8.2.)

Components of Subdivision Ordinances

Subdivision ordinances perform several specific functions. Of paramount importance is the adoption of design, construction, and material standards for facilities that serve and support the project and continued development of the larger community. Although jurisdictions vary on the listing of systems addressed by their subdivision ordinances, the most typical features, systems, and facilities are as follows:

- Street design, including arrangement, right-of-way and pavement requirements, geometric design, intersection design
- Sidewalk and trail design
- Street and traffic control signage
- Parking standards and geometrics
- Storm drainage and stormwater management system design, including inlet, pipe, manhole, swale, pond, culvert, and outfall
- Water distribution system, including trunklines, mains, and laterals
- Sewage collection, including trunklines, mains, laterals, and pumping stations
- On-site and small off-site sewage treatment design
- Utility system and easement design
- Erosion and sediment control design
- Lot and open-space grading requirements
- Installation of survey monuments and markers
- Protection of environmental and historic features
- Landscape and buffer requirements

Subdivision requirements are intended to offer protection to consumers, who have a perception of the quality, design, and functionality of a project that has been or is planned to be developed whether it be commercial, indus-

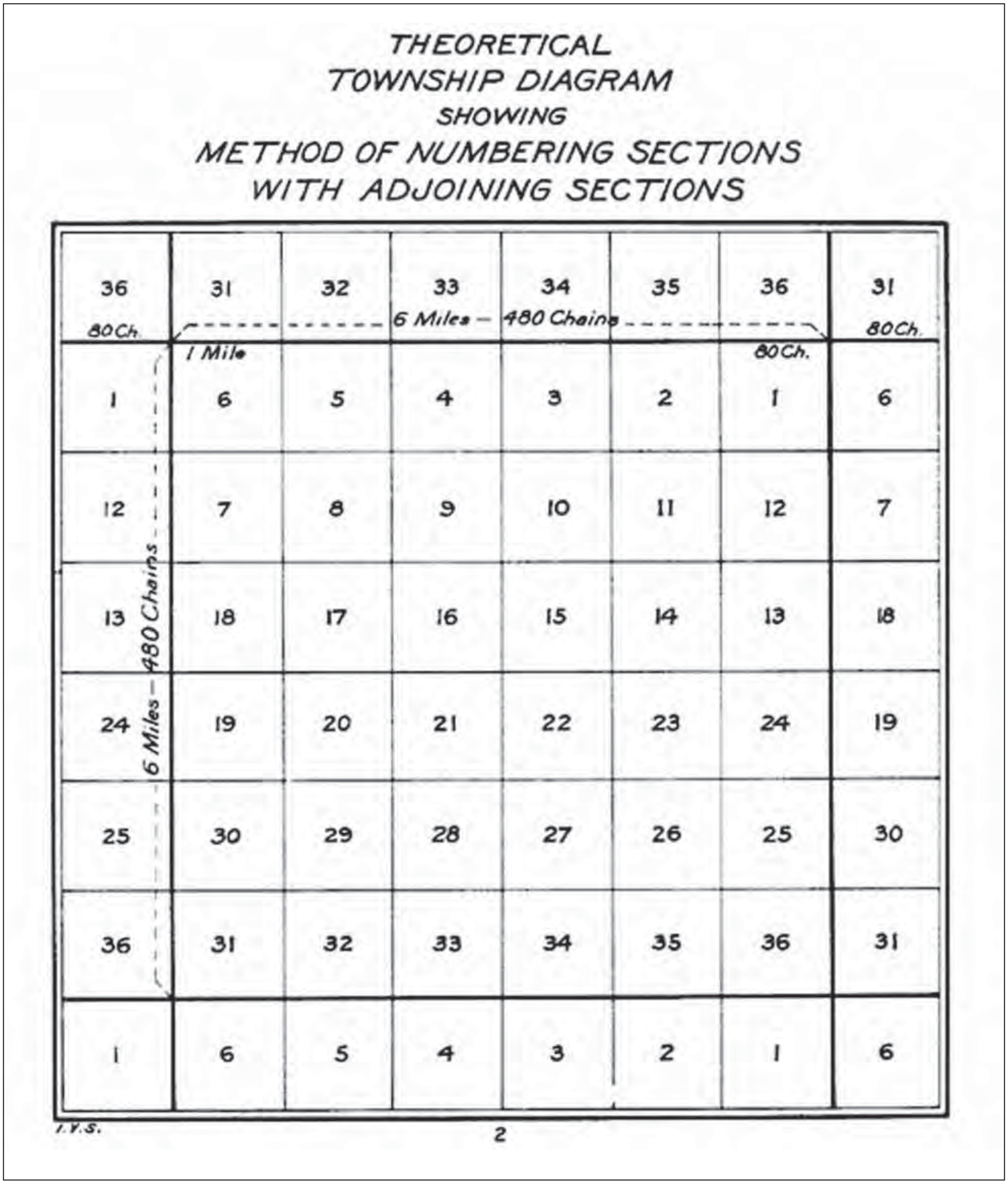

FIGURE 8.1 Theoretical township diagram.

trial, or residential. These requirements provide assurance that systems will be adequate and working at the time of purchase and that the investment is sound relative to public infrastructure. Standards provide for safe and proper design of transportation facilities and other critical public facilities, such as adequate and safe water supply and sewer capacity.

A jurisdiction desires protection because it will own, operate, and maintain many of the facilities provided by the developer. By setting minimum standards, the jurisdiction can better predict life-cycle maintenance costs and avoid costly reconstruction of otherwise less-durable facilities. Maintenance and repair are made easier because the ordi-

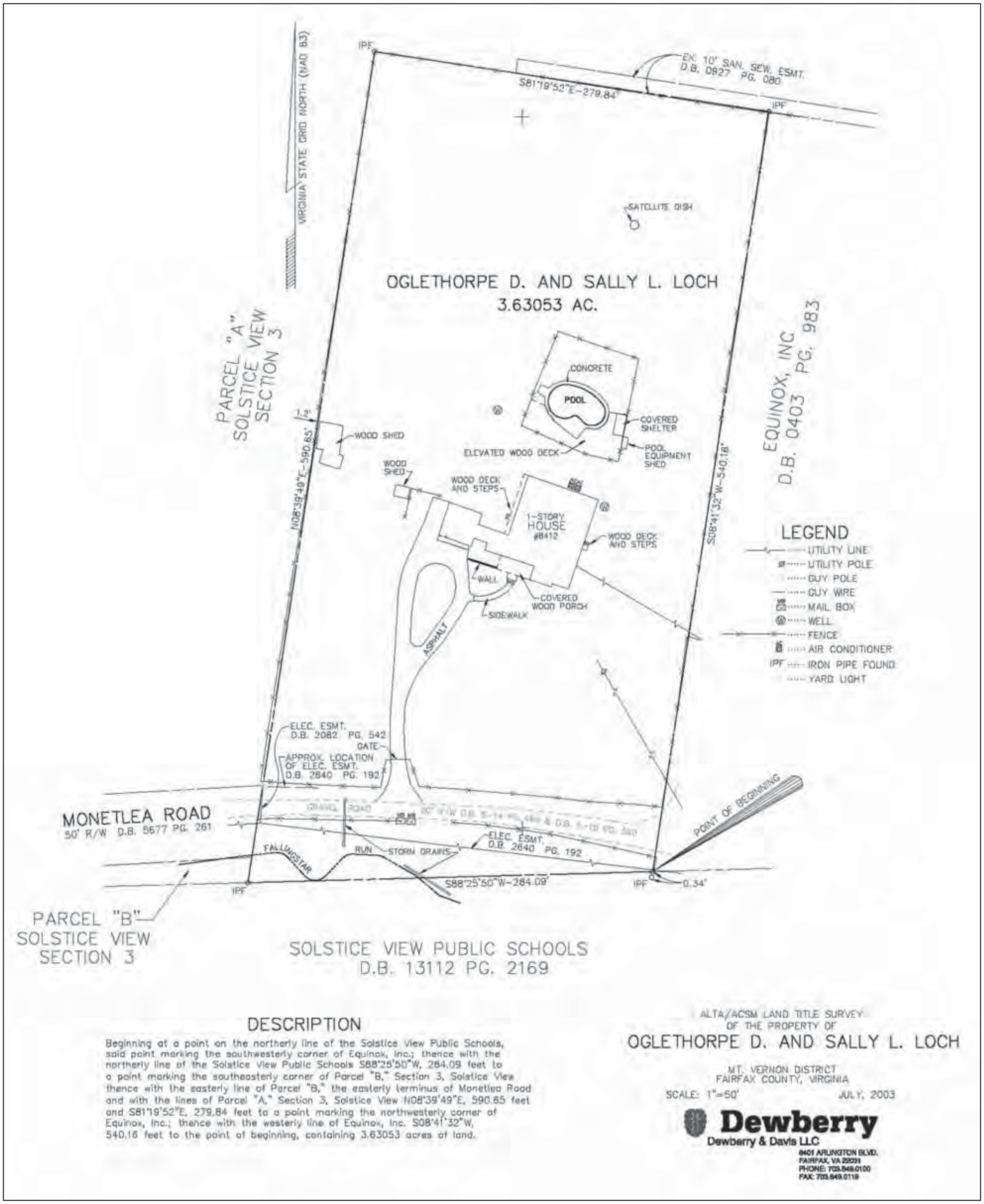

FIGURE 8.2 These plats show (*a*) the original boundary survey of the parcel containing a single dwelling unit and (*b*) the subdivided parcel including eight lots and three (open space) parcels as well as requisite easements and ROW dedications for public infrastructure improvements. Note: Plats have been modified for content and are intended as illustrative of the subdivision concept.

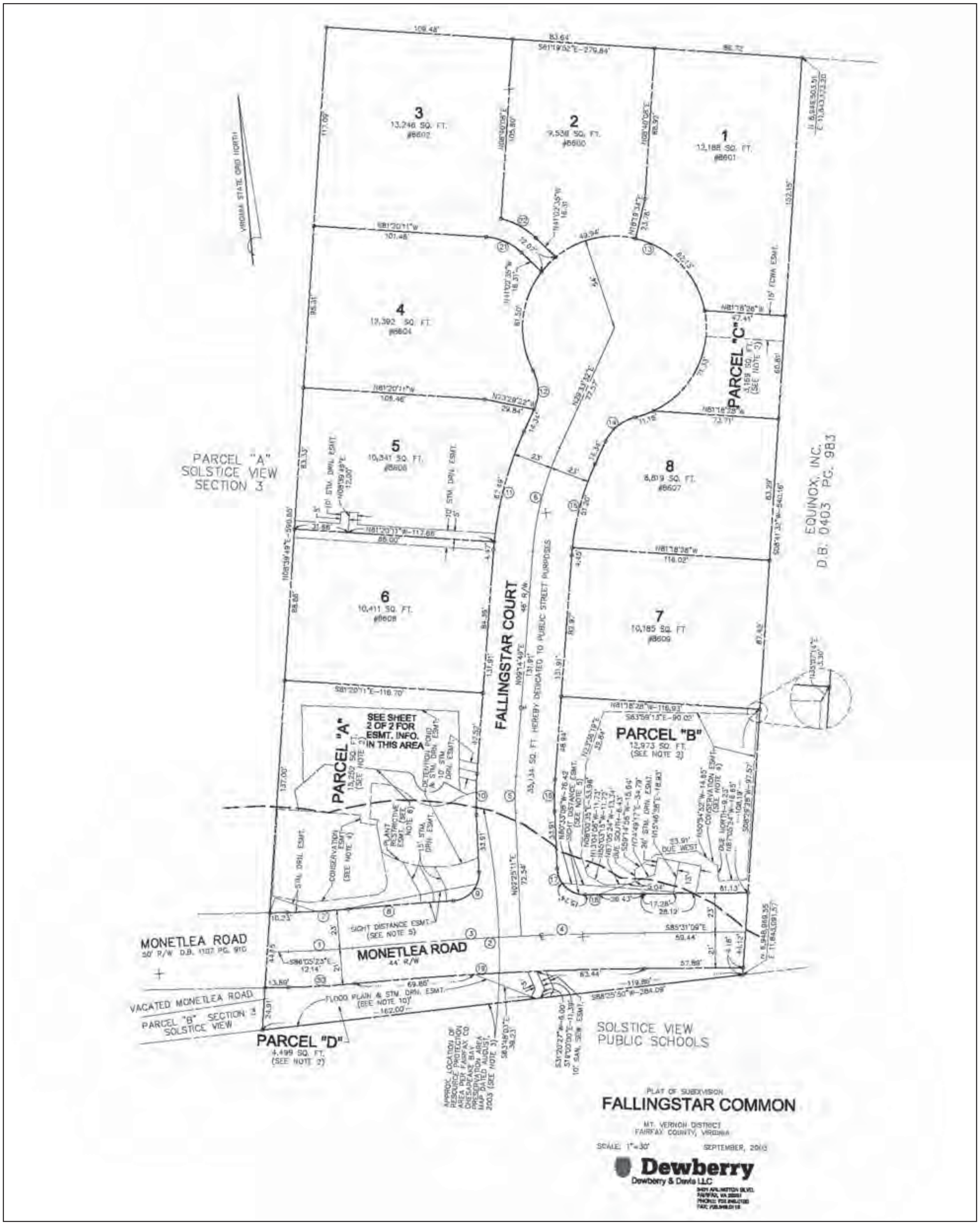

FIGURE 8.2 (*Continued*)

nances provide for a record of the design of roads and drainage facilities. Final construction documents record the location of underground utilities. In addition, the ordinances help achieve continuity and compatibility of systems. Since a residential or commercial subdivision is part of a larger neighborhood and community, the infrastructure and public facilities must coincide efficiently with the entire pattern. Not only must new development connect with the existing community, it must anticipate, and in some cases serve, future development. R. Anderson in *American Law of Zoning* (sec. 19.36, 1968) notes:

> Subdivision controls are imposed on the supportable premise that a new subdivision is not an island, but an integral part of the whole community which must mesh efficiently with the municipal pattern of streets, sewers, water lines, and other installations which provide essential services and vehicular access" (Mandelker, 1985, p. 508).

Public infrastructure design criteria and construction standards ensure that the public facilities and transportation network are compatible from one project to the next. Provisions in the subdivision ordinances address nearly every component of those systems to ensure that individual projects do not disrupt the community. For example, improperly designed and located driveway entrances and intersections can create hazardous situations, which may severely impair the efficiency of the transportation network. Similarly, stormwater management systems can cause flooding and damage on both upstream and downstream properties if those properties are not considered in the design. Literally every component of a development project has an effect on neighboring properties and the surrounding community. During the construction of one project, uncoordinated development on adjoining properties can have severe consequences.

Development Management and Review

Subdivision ordinances fulfill an important management function for local governments through the review of development proposals in an organized, efficient, and uniform fashion. This is important not only for local governments but for the development and business community as well. When consistently administered, these ordinances provide a degree of predictability in a very unpredictable aspect of business. The ordinances set forth minimum standards for preparation and submission of design and construction documents and set clear administrative procedures for their review. This makes it possible to budget for labor, both in number of workers and level of training as well as facilities. Review personnel can operate with greater efficiency, since they can expect similarity in document format and completeness in the information provided. Even requirements as mundane as sheet size and number of copies for applications can be included that facilitate storage, handling, and distribution to those who must review applications.

In most municipalities five general stages of review and approval can be expected as a part of the development review process. It is important for the development and business community to recognize that the timing of these stages can take several months to several years of processing depending on the nature of the project and the administrative requirements of the jurisdiction. The importance of understanding the development review and approval process a municipality uses cannot be overstated. While the names of the stages are different in various parts of the country, the underlying intent and staging are fairly consistent and proceed as follows:

1. Entitlement review includes the processing of one or more of the following: preliminary (subdivision) plan, site development plan, landscape plan, and resource conservation plan. Approvals at this stage establish yield, floor area ratio, type, size and location of structures, streets, lots, parking, stormwater facilities, utilities, open space, and landscaping, and the provision of exactions or proffers for public improvements (see Chapter 10 for additional information). Entitlement approvals are not a guarantee of subdivision approval but designate the literal intent or spirit of what is to be expected during all subsequent stages of project review, including subdivision plat review.

2. Construction documents—detailed engineering, landscape architecture, and surveying plans—are prepared and submitted in stage two. These plans are based on the approvals received during the entitlement review process. The purpose of this stage is to finalize how each of the development components relates to the others and will be constructed. The entitlement stage is predominantly planning intensive, while the construction document stage is engineering intensive.

3. Plat preparation, approval, and recordation in the land records occurs once development review agencies are comfortable that all subdivision requirements have been appropriately documented in accordance with local development practices.

4. Permit acquisition is the stage in which construction cost estimates are approved, letters of credit or bonding requirements are fulfilled, and grading, stormwater, and other site permits are issued. Depending on the jurisdiction, building permits may be issued concurrent with site permits or after all "wet" utilities, curbs, and street paving are installed and approved.

5. Closeout is the final stage of development and entails as-built drawings, final construction inspection/approvals, public street acceptance, and the return of letters of credit or bond release.

Further explanation of these stages can be found in Chapter 30.

Guaranteed Performance

Subdivision ordinances usually include provisions requiring the execution of performance and maintenance guarantees, such as bonds, letters of credit, cash escrow accounts, or similar financial instruments, to underwrite the installation of public infrastructure. Often, performance guarantees are set at 110 percent of the approved construction costs to help ensure municipal oversight expenses are allocated in the event the developer defaults and the bond or letter of credit is called upon. Performance bonds are often not released until after a project is completed, occupied, or accepted by public authorities. This ensures that infrastructure will be finished, maintained, and, if damaged, repaired by the developer. Both consumers and the jurisdiction are protected from incurring these expenses. Many municipalities also allow for a reduction or replacement of the performance bond when all wet utilities, grading, and paving are installed, with a maintenance bond. Maintenance bonds are used to ensure quality of workmanship and cover repair costs if a developer defaults after the project is substantially complete.

Most jurisdictions allow residents and business to occupy buildings before all of the land development improvements are completed. In larger projects, this practice allows the developer to balance income and expenditures throughout the construction period. This also helps reduce damage by construction equipment to finished improvements, such as curbs, storm drain inlets, and street pavement.

Bonds guarantee construction of public improvements in accordance with approved plans. The financial institution that issued the instrument makes funds available to the local government if the developer is forced to abandon the project. The municipality is then able to construct the improvements if the developer is unable to complete them. Institutions that issue performance bonds usually examine the creditworthiness and past performance record of the developer, and typically charge substantial fees for their service and risk. The bond instruments have the effect of committing the capital and credit available to the developer for future ventures. This provides strong motivation to complete a project and fulfill the obligations of the bond so that it can be released.

Durability of Information

Subdivision ordinances enhance the clarity and durability of information about property ownership and transfer. It does this by setting standards for property description, control of field surveys, property boundaries, easements, and other information related to property ownership. Filing final subdivision plats and related information in permanent land records of the jurisdiction simplifies the conveyance of ownership for lots and parcels. In addition, the information contained on the plats serves as public notice to future occupants about conditions and requirements affecting their occupancy. The act of recording plats among the land records finalizes the subdivision of land.

Benefits to the Land Development Design Team

Development ordinances impose considerable cost and time constraints on the land developer; however, when consistently applied by local officials the ordinances can offer protection to land developers. Land development is an extremely competitive industry in which many firms and individuals operate. Subdivision ordinances establish a uniform standard of plan processing, design, and construction to which all developers must adhere. Competing firms that provide an otherwise similar product cannot undercut prices by using a lesser standard of infrastructure. In addition, the ordinances offer a predictable framework for allocating development costs. While these benefits may be self-evident, it is important to point out that nearly every jurisdiction has its own nuances to subdivision ordinances. For this reason, most developers choose to operate in only a few jurisdictions and often focus on only one.

Most subdivision ordinances also set maximum time limits within which the local government must act to approve or disapprove the submittal. Where properly applied, these ordinances can guard against costly project delays and affirm that plans will be reviewed in a timely and predictable manner. Such provisions also ensure that jurisdictions maintain adequate staffing levels based on projected workload volumes. Mandatory time limits also prevent unfair treatment of developers, since reviewing authorities cannot set aside a plan viewed to be unfavorable for an indefinite period as a tactic to discourage or delay a project.

For the land development consultant, the ordinances define essential parameters that help to guide, or in some cases constrain, the project site design. In some regards, they eliminate the need to perform original research and analysis, expediting project design and budgeting. Information concerning plan processing also guides the preparation of project work programs and budgets.

Related Development Ordinances

All levels of the development community—locally, nationally, globally—have experienced a heightened concern with respect to the effect of land use on the environment. Attention has focused on the flooding caused by the clearing, grading, and subsequent paving required to develop land and the inadequacy of design efforts and regulatory practices for stormwater and site runoff. Early storm drainage requirements led to the design of systems intended to collect and carry site runoff quickly, without regard to downstream property. Recognition of the negative effects of this type of system for many applications has led to the adoption of stormwater management ordinances requiring on-site collection, trapping, and slow release or infiltration of storm runoff. Stormwater management facilities have become a common feature in land development, particularly in ecologically sensitive areas or coastal watersheds.

Concern about sediment damage from all land-disturbing activities, agriculture as well as urban development, has led to the adoption of grading and erosion and sediment control ordinances. Often made a part of the subdivision ordinances, a stormwater management ordinance, or adopted as an independent ordinance, these provisions require greater care in both design and construction of site facilities.

Local, state, and federal legislators continue to focus on the impacts of land use on ground- and surface water quality and quantity. Water quality has been found to be degraded not only by sediment runoff, but by the many chemical and metal by-products of both agricultural and urban activities. Coupled with greater interest in the use of natural features, such as wetlands to filter runoff, greater investigation of environmental impact is now required by many communities.

Many jurisdictions now have tree or other, similar resource preservation ordinances; for instance, Maryland has a statewide forest conservation regulation. Maryland's forest conservation regulations are designed to protect existing natural resources by requiring preservation of existing forest areas and/or the creation of forest areas when little or no forest currently exists on a property. Minimum forest coverage thresholds have been established based on the land use designation of the area to be developed. The regulations allow for the categorizing of existing and proposed forest areas, which allows for the protection or enhancement of higher-priority areas over areas that are deemed of lower priority. The result is that considerable amounts of forest area have been protected or reestablished as a part of the subdivision process.

These issues and others have led to an evolution in site-planning practices. They have been altered to the point where the land development consultant must consider the size and placement of permanent facilities during the design process. In addition, sensitive environmental features now play a more central role in project layout. Where they must be preserved, either by regulation or by good design, they are a key factor in decisions about project feasibility. Rather than being viewed simply as constraints, creative land development consultants and developers have begun to view environmental features and historic facilities as an opportunity to enhance project appeal and marketability.

In some regions, the link between land use and the environment has been made stronger where the latter's degradation has been shown to threaten a significant economic resource. Comprehensive programs to protect these features seek to balance private property development rights with broad public and economic concerns. Two examples of this are in Texas, where protection of ground water recharge areas is a high priority, and in the northeast's Chesapeake Bay region. In the latter case, administrative subdivision reviews are being supplemented, and in some cases supplanted, with more extensive discretionary reviews. The goal is to ensure that land-disturbing activities, such as clearing and grading, are kept to absolute minimums. The land development consultant must design protective devices with greater efficiency to prevent pollutant and sediment damage. In some cases, public policy shifts toward allowing greater flexibility in project design have failed to occur. This places a greater challenge on the land development consultant to recommend design solutions that achieve these public objectives in a cost- and time-effective way.

What to Look For and How to Use Subdivision Ordinances

- As with other ordinances, obtain the most current version of the ordinance. A facilities design manual usually supplements the subdivision ordinance and provides policies, standards, and design details for the various methods and requirements for construction within the jurisdiction. The manual may be an independent/separate document or may be a section contained in the ordinance. The community amends these from time to time, by either administrative or legislative action, with the latter being preferable. It offers an opportunity for dialogue with the governing body on the need for and cost-effectiveness of new standards and procedures.

- Identify and compile other ordinances, related regulations, or subordinate documents referenced in the subdivision ordinances that control the physical development of land. These include stormwater management, grading, and erosion and sediment control, lighting, and tree preservation or open-space ordinances.

- Note the effective dates of ordinances and amendments, as they may have different applications or may exempt preexisting conditions. Policies concerning existing recorded plats for otherwise undeveloped subdivisions vary. These plats sometimes predate even the earliest version of ordinances or more restrictive ordinances that might now be in effect. Whether or not a project can proceed and what required public improvements apply vary depending on the jurisdiction. In some jurisdictions, plat approvals have an expiration date if no development takes place. *Grandfathering,* or exemption of projects from later ordinance changes, is discussed in Chapter 9.

- Some jurisdictions provide exemptions for certain types of developments. Among those often excluded are so-called minor subdivisions that sever one or two parcels from a larger tract. Ordinance or local policy may define a tract using the parcel boundaries as they existed as of a certain date. Family conveyance provisions may allow for a certain number of gift lots to be given to immediate family members. The ordinance may exempt large lot subdivisions and permit estate or agricultural use of these properties. Boundary adjustments between adjoining properties and divisions caused by government condemnation are also frequently excluded from full compliance with subdivision ordinances. Simple plat preparation and recordation procedures often apply to these exempted divisions of property. Minimum standards to protect public health and safety may also apply.

- Identify sections of the ordinance that address site-planning and design criteria.
- Identify provisions addressing system construction standards.
- Identify ordinance provisions regarding application requirements and preparation of submittal documents. These contain specifications concerning drawing size and scales, required information, number of copies, and distribution. The design team may be required to post signs and mail notices to adjoining property owners and other interested parties.
- Procedures for administrative waivers of certain requirements, appeals, and judicial challenges to administrative or legislative actions by agency personnel or the governing body are described in the ordinance.
- The ordinance or related documents describe fees required from the land developer for review of applications.
- Identify provisions for execution of performance bonds and bond release procedures. These include preparation of as-built drawings.
- Identify the typical timeline associated with each stage of the subdivision review process, along with appeal period times.
- Familiarize yourself with the typical subdivision review process flowchart. Each municipality will have its own subtle processing nuances.

SITE PLAN REGULATIONS

The phrase *site plan* has several meanings. In its generic sense, a site plan is a graphic representation of the layout of buildings and facilities on a parcel of ground with its detail, accuracy, and scale dependent on its purpose. Although *site plan* is sometimes used synonymously with *development plan,* many jurisdictions attach a more discrete meaning to *site plan.* The differences are based largely on the specific language of the enabling legislation given to local jurisdictions by their state legislatures. The land development consultant must become familiar with the local definition for *site plan* and the implications it has for the client's development project. Many subdivision ordinances refer to a site plan simply as one of the items of information included in an application submitted for review. Its form and purpose are usually prescribed in the various ordinances administered in the community, and the level of detail required may vary among ordinances even within a single locality.

In some jurisdictions, a site plan is a separate administrative instrument apart from other development plans. Its purpose is to ensure that construction projects are accorded the same level of review and are subject to the same standards of performance as subdivision plans. In communities without site plan review authority, a development that does not fall under the definition of *subdivision* need only show compliance with the building code and zoning ordinance. This would apply to many apartment projects and most freestanding office, commercial, or industrial structures. Absent controlling regulations, on-site private facilities are designed at the discretion of the land development team, with only a cursory review during the building permit stage. When subject to the site plan process, however, these developments must fully comply with both zoning and infrastructure standards, just as if they were actual subdivisions. In some cases, developments are subject to both subdivision and site plan process, which may result in repetitive reviews. In such cases, the subdivision processing is aimed at ensuring compliance with the zoning ordinance, producing durable records of ownership and proper consideration of fees and exactions. The site plan process provides control of on- and off-site infrastructure, access, and other features to ensure compatibility and connection with the larger environment.

Some jurisdictions refer to a site plan as having a special role in securing development approval. It is neither a technical subdivision plan-type document given an administrative staff review nor an elaborate rezoning application given extensive public hearing by the governing body. It is somewhere in between, and usually applied in circumstances demanding greater control to guard against incompatibility.

In Montgomery County, Maryland, for example, the site plan is used when the zoning ordinance specifies some discretionary authority in the physical arrangement of a project. One of the county's ordinances, for instance, calls for the mandatory provision of affordable housing in projects with more than 50 dwelling units with an automatic density bonus. Normally, a site with residential zoning would require only subdivision and construction plans, approved administratively. However, the increased density triggers the requirement for site plan review. This gives the professional staff and the county's planning board greater leeway to consider a project's internal physical arrangement and relationship to its neighbors. The ordinance describes the information that must be shown and the parameters within which it must be reviewed.

The Montgomery County, Maryland, process contrasts with that of Arlington County, Virginia. In Arlington County, both the planning commission and the county board review the site plans, and public hearings are held as part of the approval process. Although the county is limited in the off-site improvements that it can require from the developer, site plans are given much the same public scrutiny as a rezoning application.

In this handbook, unless specific reference is made to a site plan ordinance, uses of the phrase *site plan* refer to the common, generic definition, that is, the design of a project layout that is the end product of the planning process.

BUILDING CODES

Building codes are adopted to protect the lives of building occupants and to guarantee safe, habitable, durable structures. While most jurisdictions adopt and modify one of the national model codes published by long-established building code organizations, some develop extensive amendments to reflect local concerns and experiences. Figure 8.3 illustrates the different code organizations and the regions where their model codes are prevalent.

With a few important exceptions, the building codes play little role in land development planning. Their primary focus is on structural integrity; fire prevention, control, and safety; suitability of materials; and support system operations. However, building codes do affect site design in three ways. First, to control the spread of fire, they place limitations on the proximity of buildings to each other and to adjoining property lines. These restrictions become important considerations in the design of clustered single-family detached homes, town houses, and multiple-building complexes, such as garden apartments. Second, to improve building occupants' chances of surviving a fire, building codes specify maximum building height, the distance a person must travel to exit a building, and the number of building or unit exits. Both height and distance are often expressed as the number of stories above grade. These may vary, depending on type of construction and presence of automatic fire suppression systems. However, the land development consultant must determine final grade elevations during the planning and engineering phases of a project to ensure these regulations can be satisfied. In addition, the location of building entrances affects placement of walkways, parking, lighting, and landscaping.

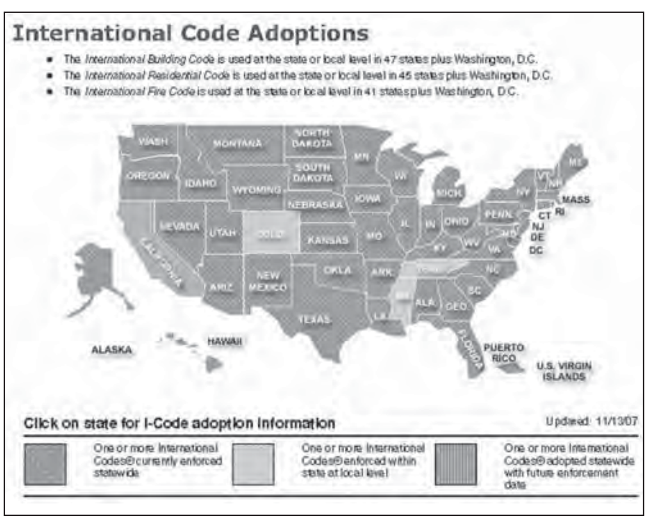

FIGURE 8.3 U.S. map indicating model code organizations' areas of influence. (Courtesy of International Code Council, Inc.)

Last, federal regulations concerning access for persons with various types of disabilities play a considerable role in site grading and development. These regulations are incorporated into building codes, which specify that ground-floor units of all apartment buildings as well as places of public accommodation and commercial facilities must be accessible. *Accessible,* according to the ADA Standards for Accessible Design (Excerpt from 28 CFR Part 36), describes a site, building, facility, or portion thereof that complies with these guidelines (referring to the standards). Taking this one step further and applying it to a site, the primary consideration from an engineering and design standpoint is the provision of accessible routes. An accessible route is "a continuous unobstructed path connecting all accessible spaces of a building or facility. . . . Exterior accessible routes may include parking access aisles, curb ramps, crosswalks at vehicular ways, walks, ramps, and lifts" (28 CFR Part 36). Accessible route provisions specify maximum grades and minimum widths for walkways as well as grading allowances, configuration recommendations, and surface treatments for ramps and crosswalks. It is important to note than an accessible route is required between designated accessible spaces; this does not mean that every possible route must be accessible, only the one designated as such. In addition to accessible routes, the standards detail handicapped parking requirements including the minimum number, acceptable location, signage, and dimensions for the spaces and passenger loading areas. For each site, the land development consultant should identify whether the accessibility standards apply and from there, determine how to best incorporate and account for handicapped accessibility. This may include preparation of an accessible routes map; special details for ramps, walks, and signs; detailed or large-scale grading plans for certain areas of the site (commonly those surrounding building entrances); and enhanced coordination efforts with the project architects.

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PART II.C. REZONING

CHAPTER 9

THE REZONING PROCESS

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INTRODUCTION

Several primary objectives guide the land development team in an effort to rezone a piece of land. Chief among these is whether the client's development program or intended use of the land can be efficiently and cost-effectively accomplished within the constructs of the permitting jurisdiction. The plan must result in a marketable project appealing in both cost and layout to the developer, the potential user, and the jurisdiction in which the project is proposed. The plan must be able to receive local government approval, which often requires development proposals that conform to the comprehensive plan.

As noted in Chapter 7, adoption of the comprehensive plan is the culmination of extensive analysis and community dialogue. Consequently, findings and recommendations in the comprehensive plan play a central role in defining the development program for a proposed rezoning. Where the plan has recently been revised, it offers a strong perspective of current community opinion. These attitudes, toward both development in general and the property in particular, are raised during the review of the rezoning application by the approving authority. Neighborhood residents are extremely diligent in demanding that their elected officials apply literal interpretations of comprehensive plan language, which they had a hand in developing. The land development team must anticipate, respect, and accommodate these attitudes.

Sometimes, however, the plan/design objectives of the developer are inconsistent with the current zoning of the parcel, the intent of the comprehensive plan, and local officials and/or neighborhood residents' visions for the property. Moreover, the desires of the local officials and/or community are not always similar to or in line with the comprehensive plan. As a result, the rezoning process, which includes input from technical reviewers, government agencies, and local citizens, can significantly affect project appearance, finance ability, economic return, design budgets, land costs, development costs, consumer costs, and market appeal. Approval procedures for development proposals, particularly those that pursue rezoning, influence the project result as much as the local development standards and principles used in project design. The most satisfactory plan for the developer, no matter how well designed, is not necessarily the best plan in the community's eyes, nor is this always the plan that gets approved.

Community involvement in the review of a rezoning proposal increases the likelihood of change from the project's original form. Resident or neighbor involvement typically surfaces during rezoning, but once comfortable with the development process and the proposed project, it tends to lessen through the entitlement process. Opposition to a given proposal is often in response to concerns regarding open space, traffic, loss of "community character," damage to sensitive environmental features, or school capacity. During public hearings, these concerns, even if addressed by the proposal, can instill lingering doubts with the decision-making authorities that may destroy or dramatically alter a project.

Similarly, residents who are predisposed against a specific land development project or even development in general, frequently succeed in influencing project design by way of their elected officials. Via letters of support or criticism, attendance at public meetings, and communications with local politicians, active, engaged citizens are directly and indirectly influencing the design and review process. Despite legal development rights associated with a property, failure to successfully manage the public review and approval process associated with rezoning efforts can significantly compromise even the most well-conceived, best-planned, and effectively engineered development projects.

For these reasons, the manner in which the development team approaches the rezoning process, with its roots in government and public relations, is as important as its approach to the technical process of analysis and design. The land development team acts as a bridge between the developer and the other participants in the land development process, such as the community residents, the jurisdiction's administrative staff, and the decision-making body. How effectively the land development team manages this responsibility is critical to a project's acceptance and approval. Communication links must be established and maintained throughout project design and review. Since communications between the other parties in the process cannot be controlled, the development team must develop rapport and support within each entity to create advocates for its plans, ideas, and objectives. This chapter discusses the analyses and procedures required to accomplish that goal.

TECHNICAL ANALYSIS OF REZONING

A developer's land use intentions frequently differ from the land use allowed by the zoning district in which the property is located. Consequently, the property must be rezoned before development can proceed. To accomplish this, the developer must demonstrate, through protracted and complex analytic and legislative procedures, that the proposed zoning is suitable for the property and that the proposed use is appropriate for the community. Even when the comprehensive plan (see Chapter 7) recommendations support the zoning change, the developer must earn the support of neighborhood residents for a project that might dramatically alter their community; this can be a formidable task.

Success in the rezoning process depends on the technical analyses performed by the land development team. Consideration of the rezoning proposal, however, frequently takes place in a politically and emotionally charged atmosphere. Private-sector motivations (i.e., the development and business community) and public-sector policies often come into conflict with each other and with local citizens' concerns and desires. Therefore, it is critical that the land development team take a proactive role in building strong community relations and support throughout the project. The rezoning process represents a major up-front expense to the land developer and comes with few guarantees that the goals of that investment will be realized. In view of the legal requirements of rezoning, the development team relies heavily on its legal consultants throughout the process. Land use/zoning attorneys are an essential component of the development team. With the advice of an experienced land use/zoning attorney, a developer ensures that technical procedures are adhered to and that government actions are consistent with the requirements of local, state, and federal laws. During the rezoning process, it is typical for the legal advisors to take the lead.

Reasons for Rezoning

From the land developer's perspective, the most prevalent reason for rezoning is to increase the land use intensity for higher yield and greater profit potential. Developing a tract to the maximum density permitted by its existing zoning does not necessarily mean profits to the developer. In fact, in some instances, development at existing zoning is not economically feasible. In a typical economic market, the highest and best use of a property is a critical factor in setting land value and prices. This land value is established based on the scarcity of developable land in general and the demand for property of similar potential. The community's comprehensive plan and zoning ordinance play an important role in determining, and subsequently obtaining, the highest and best use. For example, a community's comprehensive plan might suggest that a 20-acre parcel of ground located near a commercial area should be developed at a multifamily residential density of 15 dwelling units to the acre. Although existing zoning allows one dwelling per acre, based on the comprehensive plan recommendation, the land's highest and best use becomes multifamily; this instance represents a great case for rezoning. (The converse is true too—meaning, if a comprehensive plan does not recommend the use the developer seeks, the rezoning will be far more challenging.) The land use value is based on the demand for multifamily development, the scarcity of multiple-family zoned land, and the potential yield of the land. The developer's successful rezoning effort is essential to the subsequent purchase of the land.

Other motivations exist for seeking rezoning approval. As noted in Chapter 7, comprehensive plans often set a range of densities and uses rather than setting a finite density. In evaluating the plan to determine potential uses, a feasibility analysis may suggest land uses for which there is considerable market demand in the area. The situation may exist where an intended use is more compatible to the surrounding area than existing uses or uses permitted by existing zoning. Further, the developer may wish to rezone because of a preference or bias for a particular type of development.

Background Investigation

The development team's initial step in preparing an application for rezoning is to conduct an analysis of the community's comprehensive plan. Many jurisdictions make a finding that the proposed zoning and subsequent development comply with the provisions of the comprehensive plan even if under the law of the jurisdiction the comprehensive plan is a guide and not a mandate for specific development. Absent support in the comprehensive plan for the new zoning classification, it is far less likely that the governing body will approve the rezoning application. Approval of a rezoning that is inconsistent with the comprehensive plan, absent sufficient evidence of rectifying an error made at the time the comprehensive plan was adopted, invites legal action brought by discontented citizens against both the developer and the public officials who approve the unsubstantiated rezoning.

Preparation of the rezoning application requires that the land design team conduct two levels of analysis of the comprehensive plan. First, an analysis of jurisdiction-wide policies, which identify the constraints and incentives, imposed during the development process. Second, parcel-specific policies, which address detailed requirements, must be incorporated into the development plan. Typical considerations are discussed here. Although much of this familiarity comes from experience with previous projects, the land development team should maintain an in-house reference copy of the comprehensive plan. This copy should be annotated to reflect recurring issues and themes encountered in previous project plan reviews to aid the land development team in anticipating future conflicts.

Each jurisdiction's comprehensive plan is unique to that community. However, the land development team should refer to the following list as a framework for identifying significant development issues, both jurisdiction-wide and parcel-specific, that must be addressed and resolved by the proposed development. Depending on local practice, these factors indicate the types of studies and the level of detail required in a rezoning application:

- *Development patterns and future land use recommendations:* These define and distinguish areas where development is both desired and discouraged, usually identifying ranges of development density, intensity, and criteria against which development proposals will be measured.
- *Adequacy of public facilities ordinances, growth management, and systems management programs:* These often suggest the commitment of financial or land resources to internal and external improvements in order to accommodate proposed development, including the location of such facilities, the timing or phasing of construction, and the impact of these factors on the development proposal.
- *Environmental and cultural preservation:* Identify the type of natural and man-made resources given priority by the community, suggesting the type of investigation needed to identify such resources and the method of protection and preservation to be used. Such criteria may affect project yield by reducing buildable land area, or they may present a unique opportunity for a site amenity or adaptive reuse scenario, thus increasing the development value. Natural and cultural resources impact project design and construction; it is up to the development team to optimize the use of these resources as a bargaining tool during the rezoning process, incorporate these features appropriately into the overall development, or to mitigate impacts as required.

The comprehensive plan's geographic and functional components also provide information directly related to the property. This information refers to specific circumstances that must exist or conditions that may be applied in reviewing development proposals. The comprehensive plan recommendations for individual parcels consider impact on the community and surrounding properties. Several factors play a role in assessing that impact and determining future use. Depending on parcel size, the ability to control development by both the developer and the jurisdiction varies. As that control increases, usually with larger properties, the developer has broader opportunities for incorporating features that make the project compatible with its surroundings. The comprehensive plan may recommend a range of land use intensities and establish conditions under which the jurisdiction considers different proposals. For example, the plan may call for a residential use range from five to eight dwelling units per acre (du/ac) with the high range of eight du/ac attainable only with the satisfaction of specific development conditions.

As part of the background analysis, the land development team simplifies project design by assembling a checklist of comprehensive plan guidelines. This checklist is instrumental in preparing the rezoning application, particularly so far as it raises issues of concern to citizens and community groups that must be addressed. The application format may vary significantly from jurisdiction to jurisdiction; however, typically included is basic information about ownership, location, existing and proposed zoning, and justification for the zoning change request. The planning staff, decision-making body, and civic groups consider all issues during public hearing testimony. Early identification of these issues by the land development team provides the opportunity to consider and resolve potential conflicts and/or contradictions with the comprehensive plan. The following list includes typical conditions and specifications that the land development team can expect to find in the plan:

- Base density or intensity recommendations for the property.
- Unique conditions imposed to reduce impacts, both created by or imposed on the development. These may include:
  - ☐ Screening, buffering, open space or landscaping, requirements beyond the minimum to protect the project or adjoining properties
  - ☐ On-site requirements for gradation of density
  - ☐ Special requirements for preserving on-site historic, cultural, geological, or archaeological features
  - ☐ Setback requirements from major roads, parks, or other features that exceed the minimum specified in the zoning ordinance or other regulation
  - ☐ Sound attenuation requirements

- Conditions imposed to justify increases in allowable density or intensity beyond base recommendations. These include:
  - Parcel consolidation to bring small tracts into a larger parcel under a single developer's control
  - On-site improvements intended primarily for occupants of the project, beyond those normally required
  - On-site amenities and services such as unique recreation facilities, open space, day care, and public art
  - On- and off-site improvements or dedication of land or contributions for public facilities and services, such as roads, schools, parks, utilities, and housing
  - Innovation in plan design or a mix of uses intended to make the project less reliant on existing community infrastructure
  - Innovations in layout and structural design to minimize the impact of off-site nuisances, such as noise
- Criteria concerning the compatibility of, or the relationship between, the proposed project and other land uses that would support and serve the development

ADMINISTRATION OF THE REZONING PROCESS

The rezoning of property is a prelude to relatively permanent alteration of a community's physical and economic structure. In view of its importance, and due to the responsibilities and obligations prescribed by local and state legislation, analysis of a rezoning application requires an intense commitment on the part of local government. The governing body must be assured that the zoning change is in the best interest of the public health, safety, and welfare and is consistent with the guidance adopted in the community's comprehensive plan. The governing body must be satisfied that development proposals accommodate the concerns raised by its constituency and resolve the issues outlined by its professional staff. In many cases, constituent concerns carry more weight than issues identified by staff.

Due to the level of analysis required, zoning applications present urbanizing communities with a tremendous workload. This is true not only for the staff but also for the elected and appointed officials who must review and render recommendations and decisions on the proposal. To manage this workload, jurisdictions often limit the time frame within which rezoning applications can be received and heard, which facilitates the allocation of review time and scheduling of required hearings. Applicants who fail to meet a prescribed deadline are forced to wait for the next period to file applications. In addition, many jurisdictions establish a waiting period before previously denied rezoning applications, which have been amended, can be refiled. This prevents the jurisdiction from being burdened by the need to conduct frequent reviews of projects submitted for the purpose of testing the waters and finding the right formula to win approval. This limitation on refiling also forestalls the submission of frivolous applications.

The development team may have only one opportunity to present its proposal. Further, typically a year or more can pass between the time of the applicant's filing of the rezoning request and the decision-making body's decision. In view of the time and expense involved in the rezoning process, the development team must take maximum advantage of the singular importance of this opportunity. This mandates overcoming potential obstacles and using all available resources in formulating and justifying the development program. Those who will review submission materials, those who approve the rezoning, and those who live near the project are perhaps the three most important resources available to the development team. The approach that has proven to be most effective in project development is the early involvement of the community, planning staff, and governing body in determining a site's development potential and the issues, problems, and opportunities for resolving conflicts. As stated earlier, processing of a rezoning application without the early inclusion of these three groups invites opposition and increases the likelihood of failure.

The Professional Planning Staff: Decision Influencers

Typically, in a growing jurisdiction, the governing body delegates the responsibility of reviewing and analyzing the rezoning applications to the professional planning staff. The staff also manages the application review process, which involves the distribution of applications to other government agencies and assembling responses for presentation to the advisory and approving authorities. In some cases, the planning staff is in a position to resolve conflicts among agency reviews. In addition, the staff frequently engages in preliminary negotiations with the development team.

As is often the case in larger communities and in those broken into smaller planning areas, staff members are assigned to geographic areas. Each may play a specialized role as coordinator for all planning and development activity. These individuals frequently oversee information dissemination and respond to public inquiry on land use, zoning, and development issues in the assigned area. These activities place the staff in a unique position and establish them as an important resource in project formulation.

The staff offers a critical communication link between the development team and the other important process participants and, consequently, the team must take advantage of this valuable resource. Staff members have access to the historical records concerning prior zoning and/or development actions. Further, these professionals are often in direct communication with elected officials whose constituency is affected or concerned about development proposals. While staff members are charged with delivering unbiased reports to the decision-making body, they are also frequently sought after by community residents and other civic groups to promote private issues. Many such civic groups are diligent in monitoring development proposals and equally diligent in attempting to build allies among local politicians and planning staff as a first line of defense in protecting their neighborhood. Last, the staff is responsible for interpreting comprehensive plans and regulatory policies and ordinances as they relate to each development proposal.

The staff can be either a powerful advocate or a difficult adversary. A staff member who becomes enthusiastic about a proposal often promotes that support in meetings with the planning commission, governing body, and even civic groups. The professional opinion of the staff, ideally, is made without the influence or burden of political and economic needs. The commitment to uphold that opinion can be strong. In addition, it might be axiomatic to suggest that the lower-ranking public planning staff, those likely to be directly involved in coordination and plan review, often assume the greatest control over development submissions. There are ample opportunities to have decisions of these professionals overruled, with both administrative and legislative actions; however, this can be counterproductive. The relationships established between staff members, the land developer, and the development team extend well beyond the geographic and calendar boundaries of a single project. By developing strong relationships with the staff, information is more readily obtainable concerning the attitudes and desires of community residents and elected officials. In addition, the staff is usually more receptive to proposals when members of the development team are perceived as forthright, knowledgeable, cooperative, and accommodating.

In working with the professional planning staff, the following questions should be asked early in the project design phase, preferably as part of the project feasibility study:

- Are there recent rezoning or development proposals concerning the subject property?
- Was the property considered during recent comprehensive plan reviews?
- In either case, what issues were raised by civic leaders, elected officials, or government agencies?
- Are the community's residents organized in their concern and consideration of development proposals in their neighborhood? More specifically, who or what organization appears to take the lead?
- Does the governing body or planning commission have members who are elected or appointed by election district? Have those members established a formal or informal network for receiving input from community residents? Have these individuals been in contact with the planning staff to discuss the subject or nearby property?
- What constituent issues or complaints relative to land development in general appear to be commanding the attention of elected or appointed officials?
- What specific recommendations does the staff member have for the future development of the property?
- What are the most critical issues raised by the rezoning application and development proposal (i.e., traffic, environmental impacts, or school capacity issues)?
- Is the staff member aware of other development proposals being considered or reviewed in the vicinity of the subject property?

The answers to these questions provide a critical historical perspective that is needed in considering the development potential and design of the project. The answers help to focus attention on those issues that could terminate or delay a project and provide important clues concerning the local leadership and decision makers in the community. Finally, by directly involving the planning staff in the project, the staff becomes a valued part of the development team. To the extent that the staff's opinions are addressed in project design, the professional planning staff may feel obligated to help in the support of the proposal in public forums.

Staff is also charged with compiling the comments of other local agencies, such as the department of public works and the state highway or transportation administration. These other agencies are very much involved in the review process. Within each agency that comes in contact with the plan, individuals familiar with specific issues relative to their expertise and program are important sources of information and potential support.

The Political Leaders: Decision Makers

The community's governing body is responsible for devising and implementing policies and strategies to manage the economic, demographic, social, and environmental resources. With respect to land use and development issues, the governing body must distinguish among development proposals that provide the greatest benefit to the community and those that impose the greatest costs. At the same time, unique relationships exist between the community's elected leadership and its citizens, and those in the business and development community. The decision-making body—and those whom they appoint to advise and implement policy, such as the planning commission—has a responsibility to consider the needs and attitudes of both of these groups. The fact that they are elected, and their terms in office are determined by the satisfaction of the electorate, can pose a significant dilemma in making land use decisions. However, many take their leadership role seriously and are willing to use that role to build support for development proposals they believe to be in the community's best interests.

The timing of local legislators' formal involvement in the rezoning process varies among jurisdictions. However, the development team should seek informal opportunities to meet with members of the decision-making body early in the feasibility analysis, particularly for large and potentially controversial projects.[1] When such opportunities become available, the team's primary objectives are twofold. The first is to provide the official with information on the project and opportunities for the community. The second is to become informed by the official about outstanding concerns he or she may have, as well as to attempt to identify any predisposition toward the use of the property. Such meetings can become useful in determining whether the official is likely to take an advocacy role in the process or conversely oppose the rezoning. These meetings also allow the official to provide the development team with key community contacts that the developer should meet with throughout the process.

The Community: Friends Not Foes

Assessing the Community. Prior to and concurrent with the review process, public hearings that have community residents and the development team standing shoulder-to-shoulder in support offer the greatest potential for successful rezoning applications. The most skillfully designed and economically sound plan can fail if the jurisdiction's elected leaders see that community support is lacking. The support or opposition of neighbors and residents is frequently a measure of how well the team communicated throughout the project design and application review process. As with the staff relationships, the communication links and established levels of trust will extend far beyond the current project's boundaries. Establishing this relationship of trust is particularly important where projects are multiphased or where the development team expects to undertake additional activity in the vicinity.

Initially, community fact-finding must be undertaken. The first step in this activity is to determine the dynamics of local community leadership. The purpose of this undertaking is to identify those community leaders whose opinions are sought after, both by other residents and by the jurisdiction's elected leadership. These community leaders are the people whose actions have an impact on the opinions of their neighbors. Ultimately, these will be the people with whom the development team must work to establish clear lines of communication. These community representatives will almost certainly become involved in the development process, whether or not their participation is at the urging of the development team. Therefore, it falls to the team to seek out these individuals with the goal of aligning favorable attitudes toward the development program. This is most successfully accomplished by involving the community early in the design process.

How community leaders share information, opinions, and attitudes with other residents, and how residents communicate with each other, must also be determined. Whether the residents are organized under formal homeowners' or community associations or are unstructured, with various individuals taking active roles on ad hoc issues, should be determined. Homeowners' associations are organizations formed by developers of new subdivisions to enable residents to manage community open space or maintain a community's amenities and common elements. As these communities become fully operational, the developer's input in the organization lessens and, ultimately, is eliminated. These associations soon become forums for the exchange of opinions on a myriad of internal and external issues that may affect the community. This is particularly true in jurisdictions encompassing a broad geographic area, such as a county, where community identity is not tied to incorporated political boundaries. Smaller associations may be linked in a hierarchical network of larger umbrella associations formed for the express purpose of monitoring development activity and government actions. In addition to organizations representing community residents living within a single development, they may also represent broader geographic subareas of the jurisdiction. This is often the case in incorporated towns or cities.

If the development team is not already familiar with the active community groups and outspoken community leaders, the planning staff can usually provide assistance in the identification of these key players in the development process. This knowledge is based on their experience from prior contacts during previous comprehensive plan reviews or nearby zoning or subdivision activities. In addition, the planning office or jurisdiction's office of community affairs often maintains a listing of formal community associations. These groups often request that they be notified about pending development applications or proposed legislation that may affect their community.

All potential sources of community interest must be identified. Residents often are not satisfied with the answers they receive from their local elected leaders. It is not uncommon for them to approach their elected state and, even, federal legislators to ask for intervention in a local issue. Members of the development team may wish to contact the offices of these individuals to learn more about the opinions and concerns of these leaders. The land development team will find it helpful to compile and maintain permanent office records about neighborhood and community leaders, particularly keeping current contact information and a schedule of regular meetings. This list should include their geographic area of interest and typical concerns expressed about development and government administration. However, the team must understand that the location of residents in support or opposition of a development proposal is not always predictable. Attitudes toward protection of various resources and community progress vary, as do concerns regarding enhanced or diminished property value.

[1]The development team's attorney should be aware of any ex parte regulations so as to avoid ethical violations. Many jurisdictions prohibit discussions going to the merits of a case after the application is filed.

Members of the governing body or planning commission may also be approached for information about community leaders. Sometimes, council, board, or commission members are elected or appointed to represent specific wards or districts within the community. If this is the case, they often have established a formal organization that advises them on development or legislative matters.

Business operators are another group that often becomes extensively involved in attempting to influence development decisions. It cannot be assumed, however, that employers and owners of businesses will be supportive of development projects, whether they are commercial or residential ventures. This faction is frequently concerned about competition from new business, compatibility, access, or other conflicts in operation. The word *residents* is used liberally throughout this text. However, a business owner, even one in a business closely aligned with the building industry, becomes a resident when a development proposal attempts to become a neighbor. As with other residents, attitudes toward a specific project reflect the way in which that proposal addresses local issues. Decision makers are often very sympathetic to the concerns of the community's business interests, reasoning that they have made a long-term financial commitment to the community. The recognition of their contribution to the community's tax base is also an important factor in considering their comments about a proposal.

The files of previous development applications, not only for the specific property but also in its general vicinity, are a valuable resource for the development team. Given the freedom of information, these files are generally open for public inspection. They often contain transcripts from previous public hearings, lists of those who have provided testimony, and letters from neighbors and groups who felt moved to comment about the proposal. File records may also contain staff memos concerning meetings with interested parties. Such research takes time, and time is not always a luxury available to the development team, which often must act quickly during the feasibility phase of a project due to land purchase contract contingencies or other time constraints.

Identifying the Issues: Working with the Community. The focus and intensity of public reaction to any development proposal largely depend on several factors that are often beyond the immediate control of the land development team. These factors include the level of frustration with quality-of-life issues experienced by residents, their dissatisfaction with the responsiveness and policies of local government, and even the workmanship of their homes and experience with its builder. Important quality-of-life issues include traffic congestion; quality of schools, parks, and recreation facilities; environmental health; and aesthetics. The resources already identified, (i.e., political leaders, staff, rezoning files) often prove to be the most easily accessible in identifying concerns with a development proposal that are likely to be raised during the review process.

After the development team identifies the appropriate community organizations and leaders, it must determine how best to approach the residents of the community in which a development project is located. The development team must understand that, in general, the public has very little concern about project economics or the role of the economic factors in designing the project. The issue of private property rights becomes secondary to perceptions about the personal impact and the welfare of the immediate community. This is often true even when a development proposal is supported by the jurisdiction's comprehensive plan as a way of fulfilling its goals. Even if the project has the support of the community's elected officials, they will be hard-pressed to justify approval when it is contrary to the desires of their constituents. Their tenure in office could be shortened if they habitually ignore the constituents' desires with respect to land use.

At the same time, the objective of the development team is to get the public to accept the project or, at a minimum, to lower the degree of opposition. The development team may never succeed in having the community fully support the project; however, it may be successful in guaranteeing that opposition is withdrawn or not expressed publicly. This type of consensus building is called *informed consent* by some public administrators and observers (Institute for Participatory Management & Planning, 1983–84, p. 16). It is generated by intentionally drawing in and actively involving all components of the community and others in the decision-making process in the act of plan formulation. If objectors can be made to recognize and acknowledge the development team's earnest attempts to accommodate concerns, opposition to the proposal may be withdrawn.[2]

The communication and education process must begin with the development team itself. Since land development is a complex and extremely involved process, the individuals playing a major role in the project must acquaint themselves with the needs and concerns of the neighborhood in which the proposed development will be located. It should be emphasized that the key individuals involved with the project at this stage, such as the developer, lawyer, planner, engineer, architect, landscape architect, and traffic engineer, should be completely familiar with the project. Initiating contact with the public to introduce the proposed project can be done in several ways. The exact means of exposing a development proposal to the public depends on the experience of the land development team, their familiarity with the area, the complexity of the project, and the organizational structure of the municipality. Therefore, it is important to assemble a development team comprising people who are sensitive to the locality's concerns; familiar with local process, ordinances, and administration of policies; and attuned to the political attitudes of the area.

[2]This condition is called SEACA, acronym for "substantial effective agreement on a course of action," by the Institute of Participatory Management & Planning, in *Citizen Participation Handbook,* 5 ed., 1986, p. II-2.

Preparing for Community Interaction: Preapplication Process. Before the team approaches neighborhood groups, it is a good practice to initiate meetings with public agencies to present a concept drawing or sketch plan of the project for their initial review and opinion. Some jurisdictions have formalized this phase, calling it a preapplication meeting. The concept plan might be a reasonably scaled, preferably single-sheet drawing of the site layout. Unless formal requirements direct otherwise, the drawing should be in very loose sketch format, to preclude possible interpretation as a firm, final proposal. Sufficient information should be provided to assist the staff in locating the property and getting a sense of its relationship to existing development and potential uses that might be experienced in the vicinity. It should be noted that, although the staff members may be generally familiar with the community, they often are not specifically familiar with all its neighborhoods and business areas. Even in small jurisdictions, it is not uncommon for staff members to rely fully on their own maps, aerial photographs, and publications. Therefore, any help the development team can offer in characterizing the vicinity of the project is useful, particularly at this informal stage. The less time staff members must spend collecting information, the more time they have to dispense it.

The following information should be shown on the sketch or included as supporting material with the proposal:

- A vicinity map, showing the location of the property in relation to the larger community.
- Relevant comprehensive plan or zoning maps showing the property and adjoining parcels and lots.
- The parcel configuration, showing boundaries and the existing topography (5-foot contour intervals are often sufficient).
- The transportation network that serves the property, including abutting and nearby roadways.
- Major utility locations, both those that serve the property and major transmission facilities that may traverse the property. Capacity assessments of water and sewer facilities are also helpful if there are questions concerning adequacy
- Suggested layout and interior road alignments, showing lots, development sites, buildings, and other major features such as open space and preservation areas. The smaller the project, the greater the detail that should be shown. On a small, 5-acre residential proposal, the sketch might show a rough road and lot layout. A larger, 100-acre planned residential development might show only major road alignment and land bays, with an indication of housing type and density.
- Calculations showing parcel size, the maximum development capacity permitted under the existing zoning and the proposed zoning classifications, and the yield expected to be achieved by the developer.

While discussions at the meeting should focus on the merits of the project, the meeting should be approached as a listening session. The development team should attempt to elicit as much information from the staff as possible. The intent is to identify information about possible restrictions relevant to the project, potential problem areas, and what the expected concerns might be from the citizens in proximity of the project's location. The professional staff is attuned to the public's concerns. Information on the issues of concern of the civic and neighborhood groups provides the developer a clue about the type of opposition that can be expected and also how the project might be structured to temper this opposition. Knowing what to expect from the citizen groups, the developer and his or her team can prepare the necessary information and strategy. Design input from the professional staff should also be welcomed. When specific staff recommendations can be incorporated in the early formulation of a project, this helps to strengthen staff support throughout the life of the project. Any suggestions incorporated as a direct result of a staff suggestion can provide the impetus for a favorable staff report.

Building Community Consensus. Based on prior knowledge of the community, its leaders, and the subject property gained through experience or background research, the development team may judge the project to be highly controversial, whether due to projected density, proposed use, or any number of other development issues. In such instances, it may be advisable to contact the citizen groups prior to sharing the proposal with public agencies. This approach can enhance the relationship, establish good rapport, and build confidence between the development team and the community. Communications with community groups must be open and forthright. The team must guard against any action on its part that diminishes the established level of trust, and it must operate with the explicit intent to listen to concerns and incorporate suggestions where possible.

Eventually, knowledge of the project will be widespread. The main objective is for the development team to be the original source of information so that rumors about a project are not circulated throughout the community. If this scenario materializes, the citizens may be misinformed and develop preconceived opinions. The spreading of misinformation can harm a project before it gets off the ground. The development team must ensure that the community becomes involved as soon as possible and has accurate information on which to base its support and/or opposition. Some jurisdictions require extensive notification in order to ensure the community is engaged in the process; as a result, community participation should be viewed as an opportunity to promote or market the project early. Groups should be notified concurrently and their issues addressed as part of the integrated design process. Dispelling the dissenting attitudes of the public can best be achieved by communication and education.

In summary, many decisions on land development projects have to stand the test of a public hearing. As a result, the project must have the citizens' support in order to have a reasonably good chance of approval by the decision-making body. Public opinion on an application is a strong element of the decision-making process. If the turnout at the public hearing is substantial and the groups are organized in opposition, the project stands little chance for approval. Unless the development team has been successful in its community relations, the entire rezoning process will be challenging and the likelihood of success severely diminished.

PRESENTATIONS

In making presentations at civic association or neighborhood group meetings, the development team should prepare a well-defined agenda and useful, professional visual aids. Presentation material might include such visual aids as mounted renderings, computer presentations or DVDs containing drawings and photos, or even scaled models. The team members may be technically proficient in their fields of expertise; however, organizing and conducting presentations for citizen group meetings requires distinctly different skills. An inherent negative attitude toward development will not be changed quickly. The team must educate the citizens about the project and the process and gain their confidence in the development team. If all members of the development team are known for their good work, the community will be more receptive to the team and the project. Conversely, if the team is viewed as one that does not keep its commitments or respect its potential neighbor, negative feelings on the part of the community are certain to surface.

In assembling the team, there should be at least one individual who is comfortable at public speaking. At such meetings, it is preferable that the development team assign a speaking role to a limited number of its members. Logical distribution of topics for presentations may not always be the best approach. Some of the development team members are there as support and to provide answers to technical or procedural questions. They are also there to absorb the issues and concerns from the citizens, in order to devise solutions for the negotiation details. The development team should know who is to speak, when, and on what topics, and to what degree of detail. Even the attire of the development team during community meetings should be evaluated. The team should consider the intended audience, to balance casual versus formal, sophisticated versus simple, flashy versus conservative, and so forth. The objective is for an outsider to gain citizen consent, support, and approval. Rehearsal and discussion of the presentation and preparation for likely questions are important. Physical layout of the presentation room, audiovisual equipment, and audience comfort should be planned in advance if possible. Anticipate the size of the crowd, and provide for overflow. When the audience cannot see or hear, impatience can lead to heckling. The presentation team must guard against perceptions that information is being withheld or that it considers the meeting to be merely a requirement in the process rather than being based on the need to share information. The development team should provide an opportunity for audience feedback. The meeting should be a forum for disseminating information on the project and identifying and addressing potential conflicts.

When organizing the agenda for these meetings, consideration should to be given to the type of project that is proposed, as different types of projects require different approaches. Although the public agencies and legislative officials might be able to offer advance information on the topics of citizen concern, the development team should realize that other issues might come up during the meeting. Prior to the actual meeting, it is sometimes helpful (depending on the audience) to host an informal gathering or social hour to view and discuss project visuals (plans, renderings, models) in a more relaxed setting in order to flush out serious objections that may be raised during the presentation.

The team should be prepared to answer questions on items such as these:

- Density—infrastructure and open-space configuration
- Neighborhood change—character, population, price range
- Traffic—demand, impact on congestion and convenience, likelihood of cut-through traffic or other unwanted traffic movements
- Proposed road and intersection improvements—pavement widths, pedestrian and bicycle improvements, traffic lights, or other forms of traffic control
- Trail systems or other forms of public open space—parks, tot lots, greenways
- Screening, buffering, and landscaping
- Disturbing activities related to the land use—noise, lighting, signs, loading zones
- Architectural style and quality
- Product price range—affordable housing, workforce housing, for sale or rental
- Demographics—school-age children, active adults
- Public facilities—fire and police stations, libraries, schools, and recreation centers
- Environmental considerations—impacts to sensitive areas, green building goals, low-impact development strategies, mitigation efforts
- Stormwater management and erosion control measures—quantity and quality control for runoff, dust, cleanup during and after construction
- Construction process—hours of operation, machinery and equipment staging, storage, haul routes

While not all of these items are required at the time of the technical review of a zoning application, the development team should, to the best of its ability, be prepared with answers, as these issues are increasingly common, especially in active, urbanizing communities with extensive development processes.

Know where the flexibility lies, as concessions will have to be made by both sides. The team may have to meet with several groups to introduce the project. Each group should be met with independently so that the team can get an idea of the issues. Some of the groups will have similar concerns, while the issues of one group may conflict with those of another. The team should identify which people in a group have the influence and arrange to meet with them.

Prior to conducting formal community meetings, an initial introduction of the project should be made to a small core group of people who represent the overall organization. The best meeting place for this assembly would be at one of the houses of the core group. The objective is to keep the group at ease and comfortable. Emotions can run high over land development issues, and the informal surroundings may tone down the emotions. The core group is the perfect forum in which to discuss the merits of the project as well as possible negative impacts. However, suggestions should be made as to how the negative impacts will be mitigated. Provide the necessary information to this core group and let them take it to their group for discussion. The development team should arrange to meet with the larger group after all the members are familiar with the project.

After initial meetings, the development team should evaluate comments. Analysis will include the practical and financial costs of modifying the plan proposal. All parties will not be satisfied with the final plan. However, if the majority of the people can be satisfied and the development team has made a legitimate attempt to accommodate outstanding issues, the project stands a reasonable chance for approval.

Perhaps the most frequent issue for the development team to address is neighboring residents' concern about the compatibility of the proposed project with existing residences in the community. This is particularly true with residential proposals when single-family attached units are proposed within or adjacent to a neighborhood of predominantly single-family detached housing. The objection is expressed most often as a fear of devalued property, with concern that a product of "lesser quality" is intruding. Underlying this attitude is the belief that income of the new residents will be substantially less than their own. Existing residents are often shocked to learn the new home prices, probable mortgage payment, and income requirements for new housing. Differing architectural treatments can be employed to enhance the new project's compatibility, even to the point of making the new structures appear to be large single-family residences. Buffering, landscaping, tree preservation, and retention of open-space areas along the project's boundaries may also eliminate fear of the new project and win community support.

Concerns about traffic congestion are also high on the list of neighborhood objections to new projects. Sometimes, those objections are withdrawn when commitments are made to improve the road network. This can be accomplished by providing street widening, turn lanes, traffic control devices, or techniques to prevent cut-through traffic from neighboring arterial roads. As with all design modifications, the cost of the proposed improvement must be balanced against expected return or investment. However, if incorporating the changes means that the plan is more likely to win the support of the community and can be made more marketable at the same time, rezoning approval is more likely to be granted.

A change to a different type of land use—for example, from residential to a commercial district—presents a different scenario. The neighbors that the development team must communicate with will likely come from a greater distance. Community associations often band together when they fear that a spreading commercialization threatens their community stability. In this case, as with a more intense residential proposal in a residential area, there are a significant number of opportunities to address important concerns by modifying a proposal to address community concerns.

Despite having successfully negotiated with the majority of the groups, there may be other individual citizens who remain strongly opposed to the project. The development team should anticipate those individuals who will publicly oppose the project and should be prepared to identify and address the specific issues revisited during public hearings. It is important to demonstrate that outstanding objections have been noted and that the development team has attempted to make all reasonable efforts to resolve them. It is advisable to document important plan revisions and compromises that have been made throughout the early stages of the project.

Presentation Information and Graphics

Facts, figures, and graphics should be prepared to support the statements made at all meetings. In view of the various levels of sophistication and understanding of land development and local process of the audience, graphics should be simple and easy to read. The development team should be flexible and, consequently, presentation graphics should imply that flexibility. Expensive rendered site plans and building elevations present nicely; however, as the sophistication of residents and civic groups grows, so does their skepticism of the information shown on these drawings. The graphics must honestly reflect the proposal, and they must be drawn in such a manner as to imply accommodation to change. If the drawings look too finished, too final, too slick, it leaves the impression that the team has little flexibility for revision in the final plan design.

In addition to the materials identified earlier for preapplication meetings with the public staff, the following are recommendations for the presentation graphics to use at community meetings:

- Development plans should be rendered (colored) to aid in visualizing the layout of roads, lots, buildings, and open space (see color insert for representative samples of renderings). Plans should be mounted on boards to facilitate their display. If meetings are large, multiple copies can be prepared for display around the room. Slide and overhead projection of the proposed development plan is also an effective means of presentation.

- To the extent possible, include adjoining homes and properties on the graphics. If adjacent property owners are expected to be present, be in a position to locate their property and refer to the owners by name during the presentation.

- If clearing of existing wooded area is proposed, show the proposed clearing line accurately. This is particularly important if the clearing line is near the property boundary and the existing trees serve as a buffer to the adjoining property.

- Show architectural style as accurately as possible; however, a qualifier should be on the elevation to allow flexibility in final architecture. This is especially true if renderings will be used during future public hearings, where graphic representations are perceived by the audience to be absolute and final. If renderings are not intended to be accurate representation of final design, that fact should be made clear and repeated often.

- To demonstrate that what is on paper is not set in stone, use overlays, inserts, pasteovers, and alternate drawings to demonstrate other design schemes, changing designs, and changeable designs.

- Scale models may be useful to represent the relationship of site massing and other features. Due to the high cost of models, their value should be evaluated against other project variables. The precautions used in preparing plans and renderings should be similarly considered in model production.

- In certain situations, it may be necessary to organize a site visit, using balloons to depict proposed building heights and skylines, and survey markers and ribbons to demonstrate building footprints and clearing limits.

- More complex or sophisticated projects may benefit from the use of computer graphics to show how proposed structures will fit in with the existing environment. "Seeing is believing"—with the capabilities of computer simulations/modeling, it is possible to bring plans to life to show transition/change in a progressive, clear way.

When it comes to presentations, and especially graphics or visual aids, be prepared. Know your jurisdiction and the level of quality/effort it requires in terms of a presentation. Effort on this front can facilitate—at times, even persuade/assuage—a contentious rezoning decision in one direction or another. (See Figure 9.1.)

Review of the Application Submittal

The review procedures followed in many communities vary, depending on state enabling legislation, local ordinance, custom, and practice. In general, applications are prepared in accordance with specific ordinance standards that specify graphic information that must be included and the format for presenting the proposal. Such information usually includes extensive analysis and studies addressing possible impacts of the new development on the community and the demand for additional public services that it will generate. Standard application forms and information checklists are usually available from the municipality's planning or zoning office (see Figure 9.2). Public notice is required by way of certified mailings and posting of the property. The notices generally contain information regarding the proposed use, scheduled public hearings, and the responsible staff person of the coordinating agency (see Figure 9.3). The municipality usually advertises public hearings in local newspapers and public cable TV, if available, as well as in community association bulletins and newsletters. The applicant must follow legislated administrative procedure to the letter, as adversary groups can delay or terminate projects where proper notice has not been given. State legislation generally mandates that action of the decision-making body must be completed within a certain specified time period, including the holding of public hearings required and the specific findings relating to the application. See Chapter 30 for more information regarding the involvement and responsibilities of the various public and private entities.

The Public Hearing and Role of the Development Team

The public hearing scheduled by the planning commission, zoning hearing examiner, and/or decision-making body is often the only formal opportunity for the development team to directly address the decision-making body to discuss their intentions and the merits of the application. In addition, this forum provides citizens with an opportunity to express their opinions about the project.

The meeting sessions during which development application-related public hearings are held are lengthy in many jurisdictions. In rapidly developing communities, the meeting agendas are often crowded with hearings for development applications that include projects of all sizes and varying degrees of impact. The hearings are often scheduled in the evening or on weekends to accommodate commission members, who may serve on a voluntary, part-time basis, as well as to increase opportunities for citizen participation. For the governing body, the public hearings may be part of an even longer agenda reflecting their role in managing the municipality. Hearing rooms are often filled with observers, applicants and their attorneys and consultants, citizens, and the news media. The proceedings may be televised for the benefit of those unable to attend. If the development team is faced with opposition or staff concerns, the public hearings frequently run for hours, as participants in

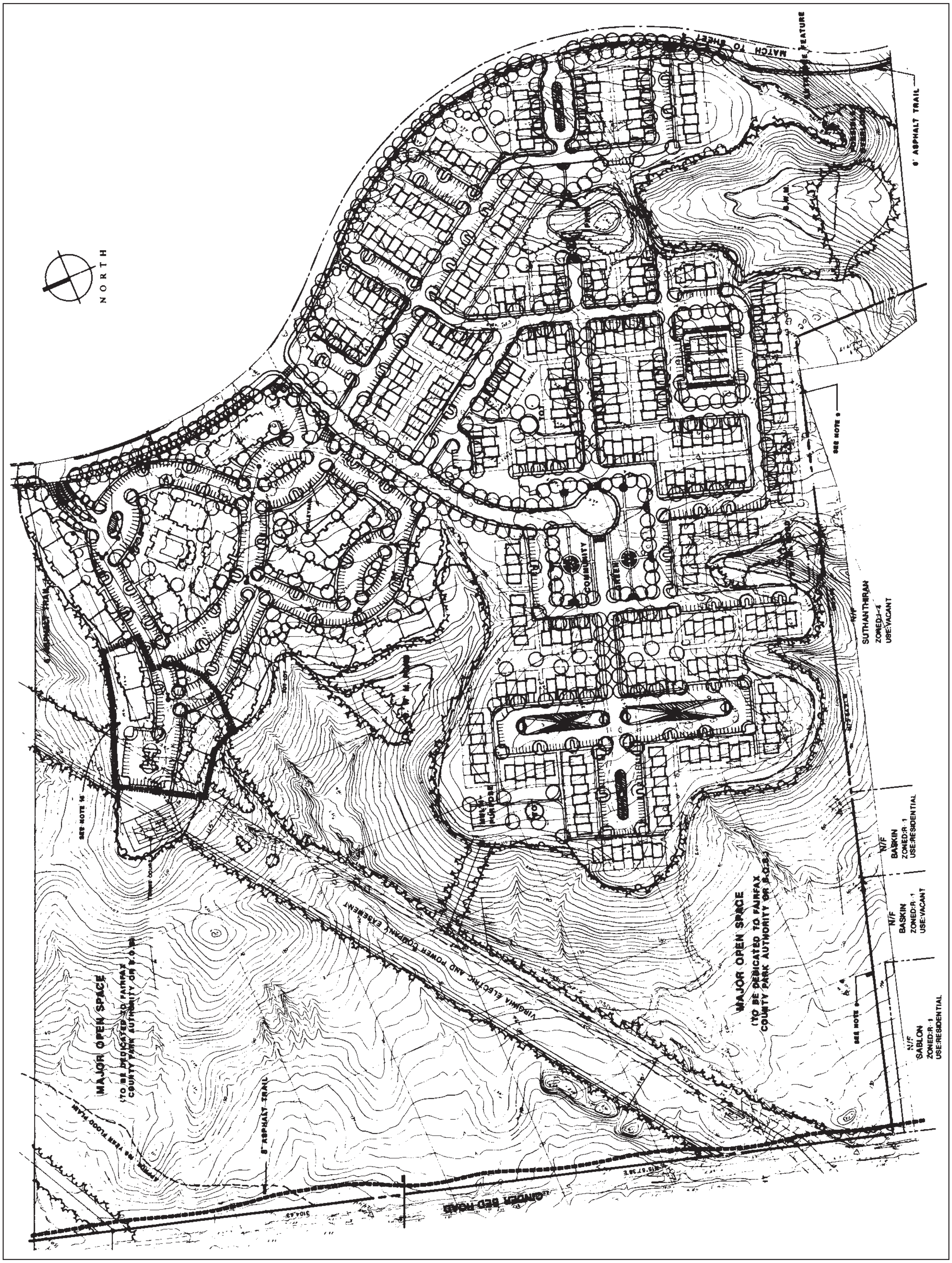

FIGURE 9.1 Three typical graphics used in community group presentations.

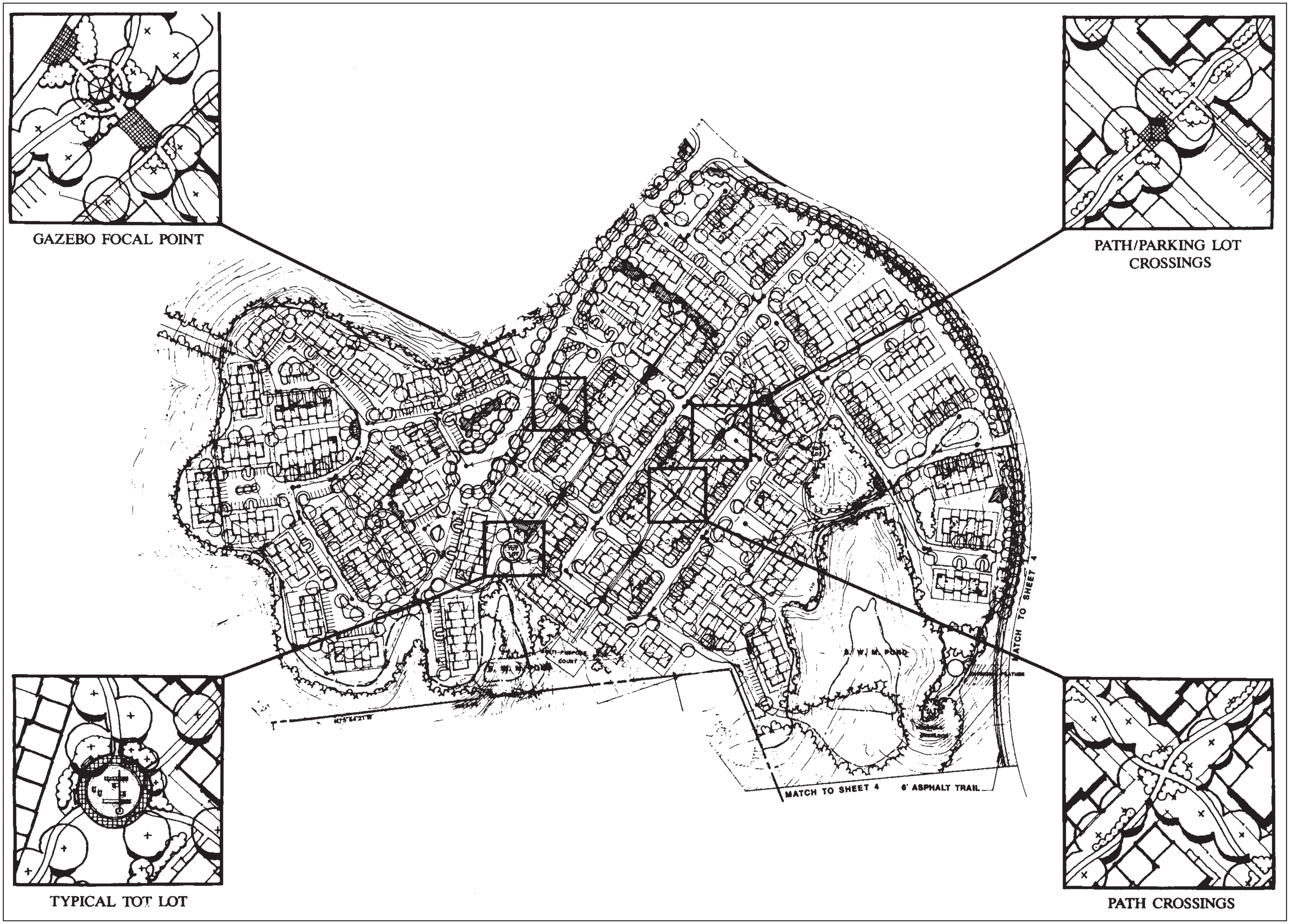

FIGURE 9.1 (*Continued*)

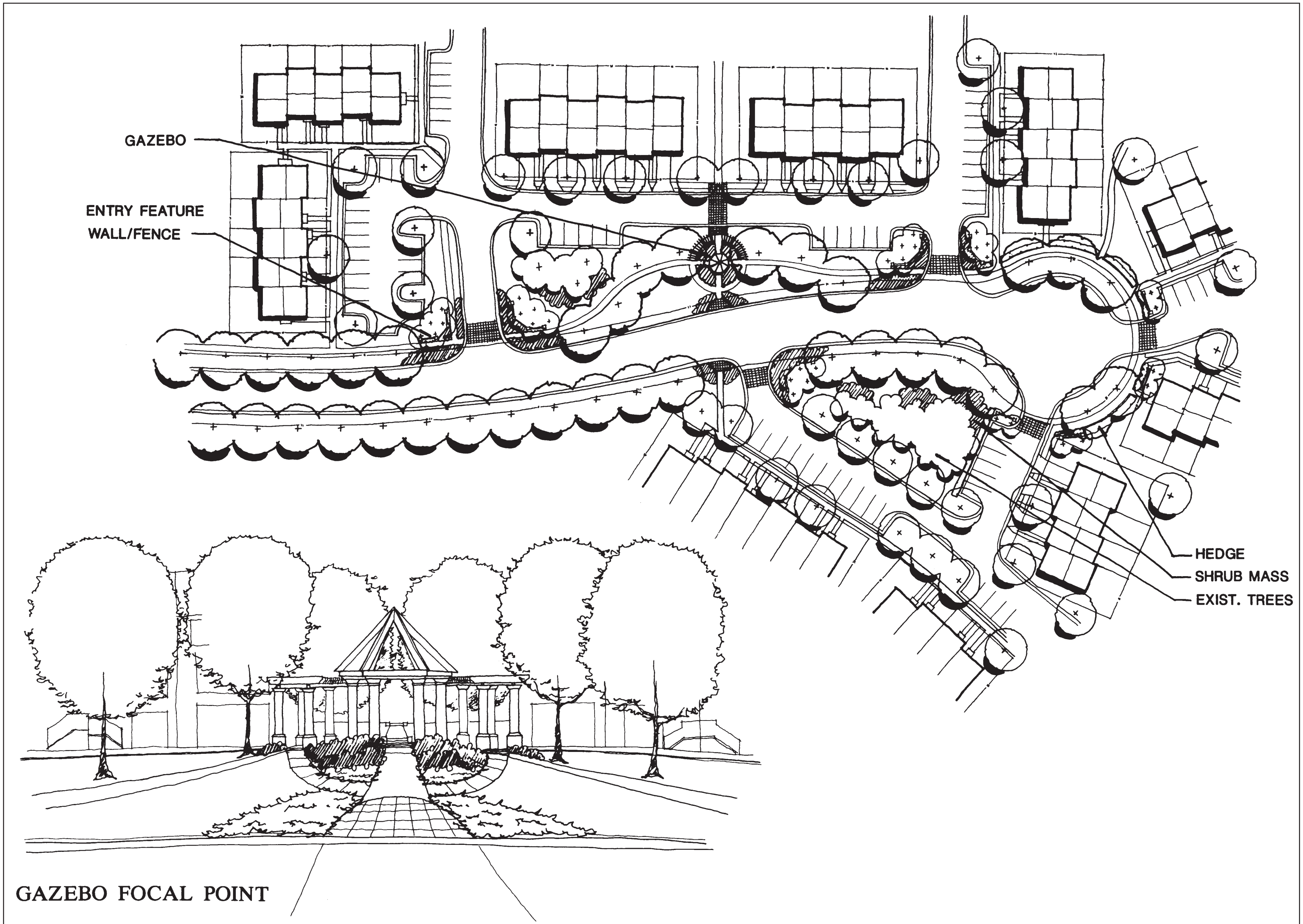

FIGURE 9.1 (*Continued*)

M-NCPPC — Development Review Division
Zoning, Special Exception and Departures Checklist

Submittal Date: ______________________

Project Name & Number: ______________________

Reviewer: ______________________

Technician Review: ______________ Date to Reviewer: ______________

Date Returned to Technician: ______________________

Date Comments Transmitted to Applicant: ______________________

Revised Plans/Documents Received: ______________________

I. PLANNING TECHNICIAN - REVIEW OF BASIC REQUIREMENTS

A. DOCUMENTS REQUIRED:

- ❑ Typed and signed Application Form
- ❑ Disclosure Statement
- ❑ Zoning Sketch Map showing property outlined in red
- ❑ Typed Statement of Justification Addressing All Specific and General Requirements or Basic Plan Text (CDZs)
- ❑ Conditions of all previous approvals, including comments from M-NCPPC Permits Office or DER violations
- ❑ Tree Conservation Plan, Forest Stand Delineation or Exemption Letter
- ❑ CB-12-2003 Affidavit of Informational Mailing (letter, "Receipt," list of addressees, & affidavit of mailing)
- ❑ State Ethics Commission Affidavit(s)
- ❑ Application Fee and Sign Posting Fee made payable to M-NCPPC: ______________
  (After completion of pre-acceptance review)

B. SITE PLAN AND LANDSCAPE PLAN REQUIREMENTS:

- ❑ Professional Signed and Sealed
- ❑ Location Map
- ❑ North Arrow
- ❑ Drawings at Same Scale
- ❑ Property Boundaries Outlined in Red with Bearings and Distances
- ❑ Zoning of Subject Property
- ❑ Total Area Calculation in Square Feet or Acres
- ❑ Adjacent Properties – Owner's Names, Lot, Block, Zoning, Use and Buildings Within 50 feet
- ❑ Location, Area, Height and Distance to Property Line for Existing and Proposed Buildings, Structures and Uses
- ❑ Dimensions of all Existing and Proposed Buildings and Structures
- ❑ Layout of Parking and Loading Facilities
- ❑ Access and Internal Circulation
- ❑ Schedules for Required Parking and Loading Spaces
- ❑ Typical Sizing of Parking and Loading Spaces
- ❑ Typical Screening of Loading Facilities
- ❑ Drive Aisles - Location, Width, Circulation and Street Connection
- ❑ Proposed Striping Method
- ❑ Lighting - Location, Height and Luminaire
- ❑ Waste Storage Areas and Typical Screening
- ❑ Typicals for Fences and Retaining Walls
- ❑ Existing and Proposed Rights-of-Way and Easements
- ❑ Street Names and Distance to Nearest Intersecting Street
- ❑ Existing Vegetation or Tree Cover
- ❑ Tidal and Nontidal Wetlands
- ❑ Stormwater Management Facilities
- ❑ Storm Drains
- ❑ Steep Slopes
- ❑ Perennial Streams
- ❑ 100-Year Floodplain
- ❑ Notes of Previous Approvals
- ❑ Current Zone Standards -Yards or Building Setbacks, Lot Area, Lot Coverage and Lot Width
- ❑ Keyed Locations of Landscape Materials
- ❑ Planting Schedules:
  - ❑ Residential Requirements
  - ❑ Commercial/Residential Landscaped Strip
  - ❑ Parking Lot Landscaped Strip
  - ❑ Perimeter Area
  - ❑ Interior Planting
  - ❑ Buffering Res from Streets
- ❑ Bufferyard Planting
- ❑ Planting Details and Specifications
- ❑ Plant Substitution Notes
- ❑ Existing Trees and Preservation Details

FIGURE 9.2 (*a*) Typical rezoning checklist; (*b*) typical rezoning application.

C. ZONING CASES ONLY – CDZ & EUCLIDEAN:

PROPERTY SURVEY REQUIREMENTS:
- ❑ Professional Signed and Sealed
- ❑ Bearings and Distances in Feet
- ❑ Zoning of Subject Property
- ❑ Adjoining Property - Zoning, Owner's Names and/or Lot and Block
- ❑ Abutting Streets - Name, Location, Center Line and Right-of-Way
- ❑ Distance to Nearest Intersecting Street
- ❑ North Arrow and Scale
- ❑ Total Area Calculation in Square Feet or Acres
- ❑ Existing Buildings - Location, Area, Dimensions and Height
- ❑ Property Outlined in Red

BASIC PLAN DRAWING ONLY:
- ❑ Physical Characteristics of the Property
- ❑ Proposed Land Use Types, Densities and Intensities
- ❑ Access and Circulation
- ❑ Relationship to Surrounding Properties
- ❑ Forest Stand Delineation

II. PLANNER - SITE PLAN REVIEW:

- ❑ Specific Special Exception Requirements - Section ____________
- ❑ Landscape Manual
- ❑ Parking and Loading Design Standards
- ❑ Parking and Loading Space Requirements
- ❑ Sign Regulations
- ❑ Zoning Standards -_________ Zone

III. PLANNER - STATEMENT OF JUSTIFICATION REVIEW:

- ❑ Specific Special Exception Requirements - Section __________
- ❑ General Special Exception Requirements - Section 27-317
- ❑ Variances from Special Exception or Zoning Requirements - Section 27-230
- ❑ Alternative Compliance with the Landscape Manual - Section 1.3
- ❑ Departure from Landscape Manual Requirements - Section 27-239.01(a)(9)(A)&(B)
- ❑ Departure from Parking/Loading Design Standards - Section 27-239.01(a)(9)(A)
- ❑ Departure from Parking and Loading Spaces - Section 27-588(b)(8)
- ❑ Departure from Sign Design Standards - Section 27-239.01(a)(9)(A)
- ❑ Conventional Zones - Section 27-157(a)

IV. PLANNER - BASIC PLAN TEXT REVIEW FOR CDZs:

- ❑ Physical Characteristics of the Property
- ❑ Proposed Land Use Types, Densities and Intensities
- ❑ Access and Circulation
  - Relationship to Surrounding Properties
- ❑ Forest Stand Delineation
- ❑ Construction Schedule (within and beyond six years)
- ❑ Economic Analysis for Retail Sales (except for MAC Zone)
- ❑ Traffic Study
- ❑ Required Findings - Section 27-195(b)

FIGURE 9.2 (*Continued*)

M-NCPPC – Development Review Division **Revised July 2007**

Prince George's County Planning Department ♦ 14741 Governor Oden Bowie Drive, Upper Marlboro, Maryland 20772 ♦ 301-952-3530

APPLICATION FORM

DO NOT WRITE IN THIS SPACE:

Application No.(s): ____________ Planning Board Review ☐ Planning Director Review ☐

Acceptance Date: ____________ 70-day limit ____________ Limit waived-2nd 70-day limit ____________

Posting Waived ________ Posting Date: ________ No. of Signs Posted: ______ Agenda Date: ________

Filing Fee: ____________ Posting Fee: ____________ Case Reviewer: ____________

Subdivision Review Committee Date: ____________

Referral Mail-Out Date: ____________ Referral Due Date: ____________

Informational Mailing per CB-12 & 58-2003: 30 days: ____________ 90 days: ____________

APPLICATION TYPE: ____________ ☐ Revision of Case # ____________
(See page 2 for a list of applications)

PROJECT NAME:

Geographic Location (give distance related to or near major intersection):

Address (if applicable)

Companion Case(s):

Total Acreage:	Planning Area & Policy Analysis Area:	Election District:
Tax Map/Grid:	Current Zone(s):	Council District:
200 Sheet:	Existing Lots/Blocks/Parcels:	COG TAZ:
Plat Book/Page:	Municipality(ies):	Aviation Policy Area:

General Plan Tier (check one): ☐ Developed ☐ Developing ☐ Rural

Proposed Use of Property and Request of Proposal:	Please list and provide copies of resolutions of previously approved applications affecting the subject property:

Applicant Name, Address & Phone:	Consultant Name, Address, Phone, & Fax:
Owner Name, Address & Phone: (if same as applicant, please indicate)	Contact Person, Phone Number, Fax & E-Mail:

SIGNATURE (Sign where appropriate; attach additional signatures if necessary)

Owner's Signature *Date* *Applicant's Signature* *Date*

Owner's Signature *Date* *Contract Purchaser's Signature* *Date*

FIGURE 9.2 (*Continued*)

ZONING CASES:	
Details of Request:	Zoning Ordinance Section(s):
Number of Dwelling Units: Attached _______ Detached _______ Multifamily ______	Gross Floor Area (Commercial/Industrial Only):

SUBDIVISION CASES – PRELIMINARY PLAN/CONSERVATION SKETCH PLAN:			
Type of Application: (Check all that apply)			
Conventional ☐	Comprehensive Design ☐	Conservation Sketch Plan ☐	Pre-Preliminary Plan ☐
Overlay Zone: Yes ☐ No ☐ If yes, provide name:			
Variation Request Required: Yes ☐ No ☐	Justification Statement Attached: Yes ☐ No ☐		
Sewer and Water Service Categories: **Existing:** Sewer ______ Water ______ **Proposed:** Sewer ______ Water ______			
TOTAL NUMBER OF PROPOSED:			
Lots:	Outlots:	Parcels:	Outparcels:
Number of Dwelling Units: Attached _______ Detached _______ Multifamily ______	Gross Floor Area (Commercial/Industrial Only):		
AREAS OF DEDICATION:			
Total Parkland:	Homeowners:	Street ROW:	Other:
OWNER:			
Last Recorded Conveyance: Grantor:	Grantee:		
Date of Conveyance:	Land Records Reference: Liber ________ folio _______		
Legal Restrictions/Encumbrances Liber/folio:			

SUBDIVISION CASES – FINAL PLAT:	
Water/Sewer: ☐ DER ☐ Health Dept. ☐	Number of Plats:
Conceptual Stormwater Management Approval No.	WSSC Authorization No.:
CSP/DSP/SDP No.:	Approval Date of CSP/DSP/SDP:
Preliminary Plan No.:	Approval Date of Preliminary Plan:
I hereby certify that the submitted final plats are in conformance with the above-referenced SP/SDP. ____ *Signature of Surveyor, Authorized Representative*	

URBAN DESIGN CASES:	
Number of Dwelling Units: Attached _______ Detached _______ Multifamily ______	Gross Floor Area: (Commercial or Industrial use only)
Nature of Revision:	

FIGURE 9.2 (*Continued*)

each case present testimony reflecting their position on the application. Controversial cases may have long lists of preregistered speakers, witnesses, and experts. At times, testimony in one case may motivate observers to participate in another case while waiting.

Prior to their meeting, members of the commission or governing body usually are given a packet of materials reflecting the day's agenda. These information packets are often lengthy, with countless photocopies of development applications, maps and plans, engineering analyses, traffic studies, and other rationales, staff analyses, and recommendations as well as letters of support and opposition. Members often engage in lengthy debate, sometimes insightful, sometimes philosophical, sometimes taking a role of devil's advocate, and oftentimes politically motivated. The questions they may ask of their staff, the applicant, or others who testify may be probing, critical, supportive, and sometimes even inane. Often the person asking the question knows the answer and merely wants it spoken for the record.

Given the incredible amount of information provided to the members of the governing body and the numerous decisions required to be made in a single session, the key task of the development team is to get the members of the governing body to focus on the development plan they have brought to the table. The governing body may know the exact location of the project or have only general familiarity with the area; consequently, they place heavy reliance on the analysis and recommendations provided by the professional staff. Due to the lengthy agendas, relatively little time is allotted to each speaker, with minimal time afforded to the development team to rebut or refute the reports or testimony of citizens or the staff. In the most controversial of cases, the citizens groups may even hire their own expert witnesses. Community residents themselves may be attorneys or traffic engineers or members of any number of professions whose testimony is given as much credence as that of the development team. The skill with which the development team approaches the hearing will have strong bearing on the outcome.

In view of the limited time given for formal presentation of the development proposal (perhaps only 10 or 15 minutes), the team member making the presentation must be well organized. He or she must establish and adhere to a well-defined agenda that focuses on the main points the team needs to make:

- The speaker should begin with a personal introduction, and describe his or her role on the development team, and introduce other members of the team who might be present. If the developer is not generally known to the board members or the public, credibility and reputation should be established. One way to accomplish this is by reference to other local projects with which the developer may have had a role or with renderings or slides of successful projects elsewhere. The presentation should include a comprehensive, yet brief, outline of the proposal. In particular, emphasis should be placed on how the recommendations of the comprehensive plan led the development team to pursue the proposal. A brief assessment of how the proposed project creates and/or satisfies economic or marketplace demand should be presented. Benefits to the community in terms of tax revenue, job creation, public improvements, and aesthetics should be addressed.

- It is important to identify the critical issues that were identified during the feasibility/technical analysis phase, and how they were addressed and mitigated. The presentation should also focus on the relationship of the proposed development to the zoning ordinance and the adopted comprehensive plan. In addition, it is helpful to discuss issues raised by the community and how the plan was revised to resolve them. Citizen support usually makes the decision making by the governing body easier.

- If a development plan is included as part of the application, a rendered version of the plan should be available at the hearing for discussion. Depending on the requirements of local ordinance, the plan should closely represent what is proposed to be constructed. It should be understood that items shown in excess of minimum ordinance requirements may become binding upon the developer. Even if not binding, their omission in actual construction may prove to be damaging to the developer's reputation.

- The team must prepare to address any and all sorts of questions that might be asked of it. For important, complex, controversial projects with high visibility, key development specialists who have been involved in analysis and design of the proposal should be present and prepared to address a myriad of technical questions. The presentation should anticipate questions and criticisms that might be lodged against the proposal by board members, citizens, or staff. Throughout the course

FIGURE 9.3 (*a*) Typical site posting; (*b*) typical public notice.

RIFKIN, LIVINGSTON, LEVITAN & SILVER, LLC

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(410) 269-5066 • FAX (410) 269-1235

1133 21ST STREET, NW
WASHINGTON, DC 20007
(202) 639-0349

January 18, 2006

Via Certified Mail

Re: Application No.: RZ-##-####
Name of the Project: **Rezoning of X and Y Property**

To Whom It May Concern:

This correspondence is being sent to you because you were identified by Prince George's County as one of the following: adjacent property owner, party of record, municipality within one (1) mile, or a registered homeowner/civic association. A Zoning Map Amendment application for the above referenced property will be submitted for review to the Development Review Division of the Maryland National Capital Park & Planning Commission ("M-NCPPC").

The property that is the subject of the above referenced Zoning Map Amendment consists of a total of **51 acres** and is located at the intersections of **X** and **Y** in **Brandywine, Maryland**. The nature of application is a proposal for commercial uses.

If you wish to become a Person of Record to this application, you must submit a written request to the Department of Development Review at the M-NCPPC, 14741 Governor Oden Bowie Drive, Upper Marlboro, Maryland 20772. Please be sure to reference the Application number and name of the Project in your request. At this time, no government agency has reviewed the applications, but **after** the applications are filed you may contact the M-NCPPC by telephone at 301.952.3530.

If you are interested in receiving more information about this application, reviewing a copy of the site plan, or meeting to discuss the project, you may contact Megan M. Bramble at 301.345.7700.

CERTIFICATE OF MAILING

The purpose of this affidavit is to certify that notices regarding an application for a Zoning Map Amendment for **X and Y Property** was mailed per Prince George's County Zoning Ordinance requirements and Development Review guidelines on January 18, 2006. Additionally, the lists of adjacent property owners, municipalities within one (1) mile, and registered homeowner/civic associations were obtained on January 9, 2006 from Planning Information Services on the Lower Level of the County Administration Building.

____
Megan M. Bramble, Esquire
Rifkin, Livingston, Levitan & Silver, LLC
6305 Ivy Lane, Suite 500
Greenbelt, Maryland 20770-6311
(301) 345-7700

Megan M. Bramble personally appeared before me, the undersigned Notary Public, and deposes and says that the attached INFORMATIONAL MAILING was mailed via certified mail to the attached List of Adjoining Property Owners, List of Civic and other Registered Associations, and List of Parties of Record.

SUBSCRIBED AND SWORN before me in the State of Maryland, County of ____________________ on this 18th day of January, 2006.

____
Notary Public

My Commission expires: ______________

FIGURE 9.3 *(Continued)*

of the hearing, members of the board or commission may call on the development team to respond to questions or issues raised by others' testimony. In answering, the respondent should use the opportunity to stress related points that may have been omitted or abbreviated in the formal presentation. Often, at the close of the hearing, the board will refer to the professional staff for concluding arguments or analysis of the presentation. Consequently, it is important to have worked closely with the staff during its analysis, as they often have the last word.

The legislative or governing body normally renders its final decision at the close of the hearing. Their decision will be based on the information presented by the applicant, advice from the staff, and commissions and testimony from the citizens. If it is believed that continued negotiations between the developer and the opposing groups can achieve greater accord, the public hearing or decision may be continued or deferred to a later date. The outcome of the vote is contingent on the response of the citizens and how sympathetic the board or zoning administrator is toward the project. It is imperative that the development team proceed through the various stages by the book, for example, all applications at the state level and local level filled out and properly submitted and proper notification given. The negotiation and hearing process may take several months, and possibly several years, depending on the complexity of the project and the number of citizen groups involved. The developer should anticipate this time frame and establish the purchase contract accordingly.

The governing body often suggests or imposes conditions or modifications that the developer must incorporate into its proposal subsequent to final certification of the rezoning application. Further, it may direct the applicant to establish communication with neighborhood groups to resolve outstanding differences, deferring its decision until the proposal is modified. Zoning ordinances usually establish procedures for anyone aggrieved by the decision of the governing body to appeal that decision in the court system. A waiting period is often established after an approval is granted, in order to allow appeals to be filed. Once this statutory period passes, the rezoning stands final.

RELATED PROCESSES

Comprehensive Plan Amendment

Sometimes the comprehensive plan is outdated and the development team believes that it no longer accurately reflects the community vision or good planning principles. This often occurs when a significant amount of time has passed since the adoption of the existing plan. In such instances, the land developer may have an opportunity to seek an amendment to the plan to reflect conditions that have changed since its adoption. Often jurisdictions initiate a zoning map amendment concurrently with such a comprehensive plan amendment. The plan amendment process varies greatly among jurisdictions; nonetheless, the opportunity to amend the plan is typically available in some form.

Specific authorization to undertake a comprehensive plan amendment might require legislative action. In undertaking a comprehensive plan amendment, the local jurisdiction undergoes a comprehensive study, and the development team is often responsible for preparing an economic and demographic inventory of the project vicinity. The land development team may then have the opportunity to propose revisions to the plan typically through staff and/or the local legislators. When the proposed amendment is prepared, notice is given to the community through mailings, advertisements, and/or posted signs. The draft CP amendment is reviewed by the professional staff and will be the subject of meetings and public hearings before the community's planning commission and governing body. Adoption of the amendment enables the developer to continue with the rezoning phase in accordance with the new plan recommendations or even to accomplish its entire rezoning effort through the amendment process, as noted earlier. This process is lengthy and uncertain, and can add as much as a year to the development process.

Special Exceptions

Preparation and review of the special-exception application are very similar to those of a rezoning. Application procedures and submission requirements are outlined in the zoning ordinance. The most significant difference is that a special exception involves analysis of a use permitted in the existing zone, while a rezoning requires a change in zoning to achieve a desired use. Special-exception review is most often focused on physical appearance and compatibility of the use within the existing neighborhood of the property. The development team must assess the financial and practical impacts of these conditions on the project. Unlike zoning changes that are specific to a property or parcel of land, special-exception approvals are specific to the applicant, with such approvals usually remaining valid for a specific period within which construction must begin and be diligently pursued. An important principle of the special-exception process is the presumption that uses specified as special-exception uses meet the intent of the zoning district subject to certain conditions or performance criteria. This presumption eliminates one of the major obstacles faced in rezoning.

CONCLUSION

The rezoning process is a political one. As discussed in this chapter, the best laid and most well-reasoned rezoning plans will face substantial challenges without the land development teams' diligent effort to obtain political and community support. With the right proposal and early community involvement, rezoning a property to achieve its highest and best use is not only achievable, but may yield mutually beneficial results for both the developer and the community. Assembling an experienced land development team is critical to accomplishing a successful rezoning.

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CHAPTER 10

EXACTIONS, INFRASTRUCTURE ENHANCEMENTS, AND FEES

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INTRODUCTION

Conventional efforts to accommodate an increasing population have often resulted in a sprawling, ill-conceived development pattern—one that emphasizes environmental and transportation deficiencies and exerts a large demand on public infrastructure and services. Consumer expectations for the quality of final products and the efficient delivery of what are considered basic services—water, sewer, proper drainage, free-flowing access, and, in today's post 9/11 mindset, privacy and security—have only increased. Providing these sometimes contradictory features within the built environment is not only a market-driven priority but often a jurisdictional requirement.

In recent decades, a significant portion of the responsibility for improving the aforementioned public infrastructure systems has been transferred from federal, state, and local governments to the land developer. This allocation of responsibility varies widely among jurisdictions. Significant differences exist in the form of the applicable regulations, timing of contributions, and the magnitude of financial commitments that must be made. In most cases, the subdivision ordinances or site plan regulations identify many of the developer's obligations, which are typically limited to on-site improvements. Some jurisdictions have adopted separate ordinances that relate development projects to existing community public facilities by tying required improvements to existing capacity thresholds or deficiency levels for systems beyond the boundaries of the site that serve the development. Typically, requirements are determined during the project approval negotiation process, usually at the rezoning or entitlement phase.

The land development team must closely evaluate the laws, ordinances, and standards of the locality in which they are proposing a development, to determine the exactions, infrastructure enhancements, and fees that can be expected. The type, form, and number of such requests or mandates for public improvements are numerous and varied in their nature and can represent a considerable expense. Depending on the size and impact of a development proposal, they can range from simple road frontage improvements to dedication of land for schools or parks. Nevertheless, whatever dedications, reservations, fees, or other monetary retributions are required, it is important that they are identified early in the process so that design and pro forma economic analysis (performed by the developer as part of the go/no-go decision-making process) can account for these exactions. This chapter highlights the most common methods by which infrastructure improvements, fees, and other exactions become part of the development process.

EXACTIONS, INFRASTRUCTURE ENHANCEMENTS, AND FEES

Exaction is the term applied to the provision that the land developer establish public, communal, and consumer benefits in exchange for and as a condition of development authorization. Depending on the jurisdiction and the type of project or plan submission, exactions may be referred to as *proffers, development conditions,* or *concessions.* More specifically, exaction includes the following activities (adapted from Frank and Rhodes, 1983, p. 3):

- Reservation, preservation, or dedication of land for public or common facilities and use
- Construction, dedication, and/or operation of public or common facilities and services

- Purchase of land, facilities, goods, and services for public or common use
- Payment of monies to the jurisdiction to defray the cost of its purchase of land, facilities, equipment, and services
- Restriction of development potential or provision of features and facilities intended to achieve social, aesthetic, or economic goals or other public benefit

Exactions add both direct and indirect costs, which must be identified in preparing project budgets. Direct costs include those costs associated with design and engineering, hard construction, direct cash payments, operating, and plan review. Indirect costs may include lost project yield and interest-carrying charges incurred in review and delay of approval. These costs are passed on to the consumer by way of purchase price or leasing fees.

The cost of providing the exaction should be weighed against the direct and indirect benefits to the occupants of the proposed development as well as the less tangible value that may be brought to the project. Indirect benefits address important public goals or mitigate an undesired impact created by the project. While the developer may incur an initial economic loss to fulfill the exaction, it is possible to recoup value, both from approval of the project and from improved marketability. Depending on the legislative authority of the jurisdiction, the proposed development may or may not ultimately create the need that the exaction will satisfy.

Land Reservation

Many communities have the authority to require the land developer to reserve private land that may be needed for public use, including parks, schools, or major road rights-of-way. Typically, the need and location of these facilities are identified in the jurisdiction's comprehensive plan or capital improvement projects budget. The land reservation prevents the total loss of these sites as their development potential becomes compromised by public infrastructure needs. Notice of the reservation usually comes during the earliest stages of project review. Depending on the size of the project, the reservation may be for the entire property or for a small portion of it. Such a reservation does not immediately involve the transfer of ownership. It does, however, obligate the developer to keep the reserved area free from construction for a specific period, during which the local government considers acquisition of the property. The reservation is typically not a gift, as the jurisdiction will actually pay the owner the land's fair market value, if it takes title to the property. Sometimes, the jurisdiction will release the reservation after considering the cost of the property, available funding sources, or alternative sites for the intended public use. This allows the developer to proceed with site development activities unencumbered by a reservation.

While the reservation may not create financial obligation or loss for the developer, the requirement sometimes creates difficulties for the land development team. The reservation creates a period of delay or uncertainty, often for several years, until the issue of property transfer is resolved. The land development consultant may be called on to prepare two sets of development plans to identify the development potential both with and without the reservation. Issues created by a reservation include the development potential or yield of the remaining land, as well as how the residual can be designed in terms of access and utilities. Further, the proposed use of the reservation portion must be compatible with the proposed use of the remainder of the property. For example, if the reservation was for a sewage treatment plant and the site was planned for large-lot, expensive, single-family detached dwellings, the marketing of such homes becomes questionable at best; NIMBYism, the "not in my back yard" mentality, is a hard preconception to overcome even for the best marketing professionals. In such a situation, the diminished value of the residual land would become part of the negotiations with the local jurisdiction.

Site design opportunities and flexibility may be severely limited depending on parcel configuration and the location of the reserved parcel within the overall site. This creates a major challenge for the land development consultant in preparing the most suitable layout for the project. Subsequent release of the reservation allows reconsideration of earlier design alternatives. However, project construction plans may have already been approved, or substantially approved, through the approval process. Therefore, the developer should encourage the municipality staff to allow concurrent processing of alternate plans, in anticipation of early disposition of the reservation. The decision to incur this expense must be balanced by the likelihood of the reservation release and the potential financial benefits from the alternatives.

Dedications

Mandatory dedication is a mechanism common to most jurisdictions and is usually among the provisions contained in the subdivision ordinances. Mandatory dedication requires the developer to transfer ownership or property rights of certain privately held lands to the governing body at no cost. Mandatory dedications, however, must not violate the Fifth Amendment's ban on the taking of property without just compensation. Land most often subject to mandatory dedication includes rights-of-way for streets and public utilities, floodplains, easements, park and recreation facilities, and similar uses. Such dedications usually are made a condition of subdivision approval. Quite often, jurisdictions seek dedications of land above and beyond that required to support the development itself. In these instances, a land use lawyer may need to be consulted.

Although the dedication is made and recorded on the subdivision record plat, the government rarely accepts the land immediately. Instantaneous acceptance could result in the transfer of maintenance obligations to the jurisdiction before construction of required improvements is completed.

Subsequent construction vehicle damage would become the jurisdiction's liability. In addition, the governing body must determine whether the property will serve the public good and provide economic benefit. The cost of long-term maintenance of the dedicated parcel is a primary factor in the government's decision whether to accept the property. Still another consideration is the fact that the transfer to public ownership also reduces the land area subject to real property taxes. Most jurisdictions advance density credit when a dedication is made.

Transfer of ownership in some cases reduces maintenance and other obligations that might be incurred by the developer or by occupants of the project. In addition to a reduction of operating and maintenance costs, dedicated features can add to the market appeal of certain projects. Often, by setting aside land for schools, libraries, parks, recreational facilities, and fire and rescue operations, the project becomes more attractive to potential buyers and the developer enhances the good-neighbor image within the permitting jurisdiction.

Perhaps the most frequent dedication is that of additional right-of-way along roadways bordering a project. The local government intends this widening to bring existing roads up to current standards and accommodate the new traffic movements associated with the project. Whether construction of improvements is performed by the jurisdiction or required of the developer, the added right-of-way improves the efficiency of the transportation system and enhances the safety and convenience of site access.

Preservation

Community residents usually place a high priority on natural, cultural, or man-made features that add to the health, beauty, or character of the community. These features may become threatened by a proposed development, which prompts the community's desire to protect them. However, the local government may not have the financial resources or legal authority needed to acquire and maintain them through reservation or dedication. To fill this void, some communities are empowered to preserve these features as an exaction in the development process.

Environmental preservation is a goal often contained in a jurisdiction's comprehensive plan. Plan language can recommend that important environmental or cultural property be set aside in lots or private open space, with covenants and restrictions that prohibit future disturbance. This language is implemented as a proffer or development condition usually tacked onto and approved as part of rezoning or special-exception applications.

Environmental and historical protections have also been achieved with the adoption of preservation ordinances that allow reasonable use of the property while ensuring that the desired feature is protected. Most common among these are historical or archaeological preservation ordinances, which may require a developer to pursue adaptive reuse or carve out the sensitive portion of the site in question from the project and preserve or incorporate it into the overall development. In some instances, developers have been required to restore historic facades as part of a larger construction effort.

Recently, communities have sought to adopt tree preservation ordinances, which limit clearing and grading on portions of the site. Although preserved areas remain in private or communal ownership, covenants and restrictions provide permanent protection against future disturbance by builders or lot owners. Such ordinances often limit the development potential of a site or may involve added costs to accommodate their provisions. These restrictions often present the developer and the consultant with unique design opportunities that can enhance a project's appearance and marketability if accounted and planned for early in the process and incorporated into the overall site concept.

Payments-in-Lieu

As noted in the prior discussion of subdivision ordinances and site plan regulations, many jurisdictions commonly require that the developer construct improvements that connect to and/or directly serve the project. Most jurisdictions tie the required improvements to a specific trigger event within the development process, such as a required permit or compliance time frame. For example, depending on local policy and industry practices, improvements should be completed prior to the issuance of occupancy permits or release of performance bonds. The required improvement and its trigger condition are typically specified in the proffer, development condition, or exaction that binds it to the development program (see Table 10.1). Specific trigger conditions allow jurisdictions to more thoroughly track required improvements and contributions.

In some instances, the jurisdiction may not require the developer to construct the improvements proposed for dedicated lands. Typically, this happens when the improvement is of little immediate value, such as the widening of an abutting roadway section where there are no existing or proposed road improvements on either side of the subject parcel. A needed facility may be located off-site, such as a major road or regional stormwater management facility that is not under the developer's control or serves a broader population. In such cases, a cash payment representing actual construction cost, prorated share, or a flat fee may be required of the developer. These various forms of payments-in-lieu, if allowed in the jurisdiction and acceptable for the required improvement, are typically specified as an alternative within the approved proffer or exaction. The jurisdiction may wait until sufficient funds are collected and available in conjunction with other developments before it actually constructs the facilities. The funds usually are earmarked for improvements that serve the project or an improvement in proximity to the project. The jurisdiction may also require or allow one developer to construct the improvements and direct subsequent developers to reimburse their prorated share of the costs.

If the project is small, the jurisdiction may also waive the requirement for land dedication. This occurs in instances where the dedication of land for facilities, such as a recre-

TABLE 10.1 Sample Exactions

EXACTION TYPE	SAMPLE LANGUAGE: *INFRASTRUCTURE PROVISION* AND TRIGGER EVENT
Land Reservation	Future Road Alignment. The Applicant shall *reserve an area of the site as depicted on the CDP/CDPA/FDP for future right-of-way (ROW) for an interchange.* Upon demand by the Board of Supervisors (BOS), the Applicant shall *convey said ROW area in fee simple to the BOS,* as generally shown on the CDP/CDPA/FDP. However, if said interchange is not funded for construction within 15 years from the date of these proffers or if said interchange is deleted from the County's Comprehensive Plan, whichever event first occurs, the Applicant's obligation under this proffer shall terminate and cease and the Applicant will be entitled to use said ROW area in any manner permitted by law.
Dedication	Urban Park. The Applicant shall *construct the improvements in the Urban Park* generally as detailed on the CDP/FDP as may be modified by coordination with the Fairfax County Park Authority and following construction, *dedicate to the FCPA the Urban Park in fee simple,* prior to final bond release.
Preservation	Tree Preservation. The Applicant shall *preserve trees on the Property* as shown on the Tree Preservation Plan prepared by Dewberry dated March 14, 1997. . . . The Applicant shall *record conservation easements for the Daniel's Run stream valley, the northern boundary adjacent to the trail, and the 25′ wide area along the Property's eastern boundary to ensure perpetual conservation of these tree preservation areas.* Said easements shall be recorded with the record plat for each phase of construction contiguous to that section of trail and/or conservation area.
Payments-in-Lieu	Utilities. The Applicant agrees to *contribute the sum of $553,000 to the City of Fairfax to be used for underground placement of existing overhead utility lines along portions of the Property's frontage on Main Street and Old Lee Highway.* Payments shall be made on a pro rata basis at the time of the issuance of building permits for each dwelling unit. These moneys shall be placed in escrow by the City in an interest bearing account to be used solely to underground such existing overhead utilities within seven (7) years from the date of issuance of the final building permit. At that time, the City shall either designate the construction of other improvements which will directly benefit the Property, subject to the Applicant's concurrence or the escrowed funds and accumulated interest shall be returned to the Applicant.
Impact Fees	School Contributions. Prior to approval of the first Building Permit for the approved development, the Applicant shall *provide documentation to DPWES that the Applicant has donated the sum of $127,500.00 to the BOS for the Fairhill Elementary School. . . .* Prior to approval of the first residential use permit (RUP) the Applicant shall *provide documentation to DPWES that the Applicant has donated the sum of $22,500.00 to the BOS for the Luther Jackson Middle School and the sum of $60,000.00 to the BOS for Falls Church High School.*
Linkage	Maximum Density and Permitted Uses. A maximum of 270 multiple family dwelling units may be provided in 2 buildings, which will also include approximately 65,136 sf of retail uses to be located on the first and second floor(s) of the North building and approximately 40,364 sf dedicated to retail uses to be located on the first and second floor(s) of the South Building. The site shall not exceed 1.35 FAR and as depicted in the tabulations on Sheet 2 of the CDP/FDP the *FAR increase over 1.2 shall consist of ADU's and related bonus density units* as defined in Part 8 of Article 2 of the Zoning Ordinance. Project density as specified in this proffer shall be reviewed and approved as part of the site plan approval process.

ation area, is disproportionately indexed to the size of the project. If the resulting parcel will be of insignificant size, the jurisdiction may offer the option of cash payment in lieu of the land dedication. In this case, the payment represents the project users' impact on existing or future facilities that will be provided by the municipality.

Impact Fees

An increasing number of jurisdictions are seeking authority to allow the adoption of impact fees. These are a direct payment by a developer to a jurisdiction and are intended to reimburse the jurisdiction's actual capital costs of expanding public infrastructure and facilities to service new development. The facilities are not necessarily located on-site and may not be used exclusively by the development that pays the fee. Coupled with the potential for double taxation and discriminatory treatment of new community residents, controversy has developed over government's increasing delegation of its obligation to provide public facilities and services in this manner.

Some communities have a long-standing, limited form of impact fee relating to the provision of water and sewer. In this case, a residential or commercial user is assessed a *tap fee,* also called a connection or availability charge, usually at the issuance of a building permit. The actual fees are derived through an elaborate analysis that projects the capital costs of expanding treatment plants, pump stations, and trunklines to serve new growth.

However, more recently impact fees are being considered for such items as roads, storm sewers, schools, libraries, and similar services. What distinguishes sewer and water service from these other facilities is, perhaps, the degree of certainty with which the demand from and benefit to new users can be isolated and quantified. Those who argue against the adoption of impact fees for roads, for instance, suggest that even where the traffic demand from a new residence is calculable, the benefit of the new roadway is jurisdiction-wide. Moreover, the inability to separate residential demand from that created by employment and retail uses further complicates the issue. Finally, many argue that impact fees for roads and schools are used to correct existing system deficiencies. These are more clearly the responsibility of government or, at least, existing residents.

Where the courts have ruled impact fees to be legal, they have adopted several controls to temper their application. Courts most often employ the "rational nexus," or relationship theory, to justify the exactions. This requires that it be possible to determine the costs generated by new development, and thus avoid charging the newcomers more than their proportional share. The costs must be uniquely and directly attributable to the development. To implement an impact fee, the jurisdiction must isolate existing deficiencies and budget separately for their improvement. Fees collected should not be commingled with general funds. They should be earmarked for use in service areas that relate to the development for which the fees are paid. Like transferable development rights (TDRs) and adequate public facilities ordinances (discussed in previous chapters), special enabling legislation is required to establish impact fee regimes.

Despite the controversy and concern that the fees can add dramatic costs to home ownership and businesses, impact fees for services other than water and sewer are proliferating. Even in those communities not authorized to collect impact fees for infrastructure improvements, they have, in many cases, imposed a "voluntary" fee to finance certain major facilities. The jurisdiction bases the fee calculation on the estimated cost of improvements needed to support the total development projected to occur within a specific service area. This total dollar figure is converted to a unit cost, using the projected number of dwelling units or nonresidential building area. Thus the fee applicable to each development project is based on project size. Typically, the fee is offered in conjunction with a discretionary rezoning process, with payment being one of the proffers or conditions attached to the approval.

Linkage

Previously, the discussion of affordable housing focused on the adoption of inclusionary zoning ordinances. These ordinances require that residential developers provide affordable, price-controlled housing as a condition of development approval. As an extension of that trend, nonresidential developers may also be required to provide affordable housing. A growing number of jurisdictions argue that new job creation in the community generates demand for affordable workforce housing—housing for office workers and other service employees. Due to high land and construction costs, it is increasingly difficult for these workers to find suitable housing in price ranges they can afford. In jurisdictions where this linkage is required, the developer must mitigate this impact, either by building affordable housing units or by paying, on a per-square-footage basis, into a housing trust fund established by the jurisdiction. Money deposited in this fund is used by the jurisdiction or its designee to purchase or construct affordable housing.

Review and Processing Fees

Most state zoning and subdivision enabling acts authorize jurisdictions to collect development review fees from the developer. These fees offset jurisdiction expenditures for review personnel. In some jurisdictions, this fee represents only a nominal fixed charge. Urban jurisdictions that perform extensive reviews often index their fees according to project size or the estimated cost of public improvements. These fees may represent a substantial expense. However, they also help to guarantee that sufficient revenues will be generated by new development. This enables the government to maintain an adequate workforce of qualified personnel. It provides some assurance to the land development team that project reviews will be timely and thorough. Some jurisdictions also impose inspection fees to offset the costs associated with that activity. These fees may be charged for inspection of the public improvement construction, as well as for the actual structure. Like review fees, these add to the cost of the development project and must be considered during project budgeting.

CONCLUSION

Public facilities range from subdivision streets to major commuter highways, tot lots to regional parks, water lines to fire stations, and sewer lines to treatment plants. As these systems reach their capacities, their ability to function efficiently or accommodate new growth is diminished. The consequences range from government leaders' frustration to dissatisfied constituencies or hazardous, even life-threatening, conditions created by inadequate facilities.

Historically, it has been the responsibility of government to provide and improve many of these facilities. Reductions in federal funding and corresponding local budget impacts, paired with increased citizen expectation for efficient service and fiscal responsibility, have led many local governments to find alternative, even innovative, ways to pay for growth. Frequently, these efforts become the subject of lengthy court challenges, as important public goals and policies often conflict with private property rights. While substantial public obligation remains, the private sector has been given an increased share of the burden. Development regulations play a critical role in allocating the costs of basic public infrastructure between private developers and a community's taxpayers and prospective consumers in an effort to fairly distribute the cost of growth.

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PART III

CONCEPTUAL DESIGN

INTRODUCTION

Conceptual design represents the initial effort of describing alternative plans that satisfy the development program goals and objectives in light of the previously identified site characteristics. It requires full recognition of the client program components, initial site assessment, site context, and planning and regulatory controls.

Sketches, functional diagrams, or concept plans illustrate a framework for the given development program. They diagram the potential distribution of land uses and major circulation requirements. The effort melds all pertinent comprehensive or master planning information with site-specific considerations to illustrate how the site might best be developed. For large-scale development, this initial cut at the design effort is often accomplished in what are termed *blob* or *bubble* diagrams. The intent is focused less on sophisticated graphic technique and more on fostering dialogue, a preliminary review and assessment, and confirmation of design direction among the design team participants. Concept plans are reviewed in the context of their preliminary implications on infrastructure requirements and environmental impacts as well as economic, functional, and political feasibility. This phase, similar to the more subjective assessment included in the initial feasibility and site analysis steps, moves from the review of general intent to actual physical diagramming of use arrangements. This level of conceptualization is generally completed prior to the investment of resources and time, resolving more detailed levels of design.

STEP 3: CONCEPTUAL DESIGN

Given there are generally multiple solutions for the design of any one site, it is common for alternative concept plans to be developed. The ensuing discussion with the development team may prompt a dialogue as to the pros and cons of the various solutions and identify design synergies or problems the designer alone may not have identified or anticipated. As demonstrated in Figure III.1, the end products associated with the concept design phase are a series of sketches or diagrams that delineate such preliminary considerations as:

- Points of site access, together with an initial alignment of major vehicular circulation routes. The principal road network should be developed in the context of any public comprehensive or master planning policies or recommendations.
- A distribution of major land use elements by type. The delineation should reflect the approximate area requirement for each use to begin to gauge the massing or relative area requirements necessary to accommodate individual program components.
- Delineation of areas mandated or desirable as open space based on the previously completed site assessment, such as floodplain, protection or conservation areas, wetlands, mature woodland, historic features, and streams and stream valleys.
- Preliminary determination of the need and location of major public facilities such as schools, parks, fire stations, and libraries, as identified in public planning documents.
- Annotations underscoring the advantages or disadvantages associated with the depicted design elements for discussion purposes and to memorialize for future reference.

While normally not a formal public submission document, conceptual sketch plans do provide information suitable for early discussions with appropriate public officials. They provide sufficient information to obtain an informal assessment of the development plan's compliance with public comprehensive and land use policies and the local political climate.

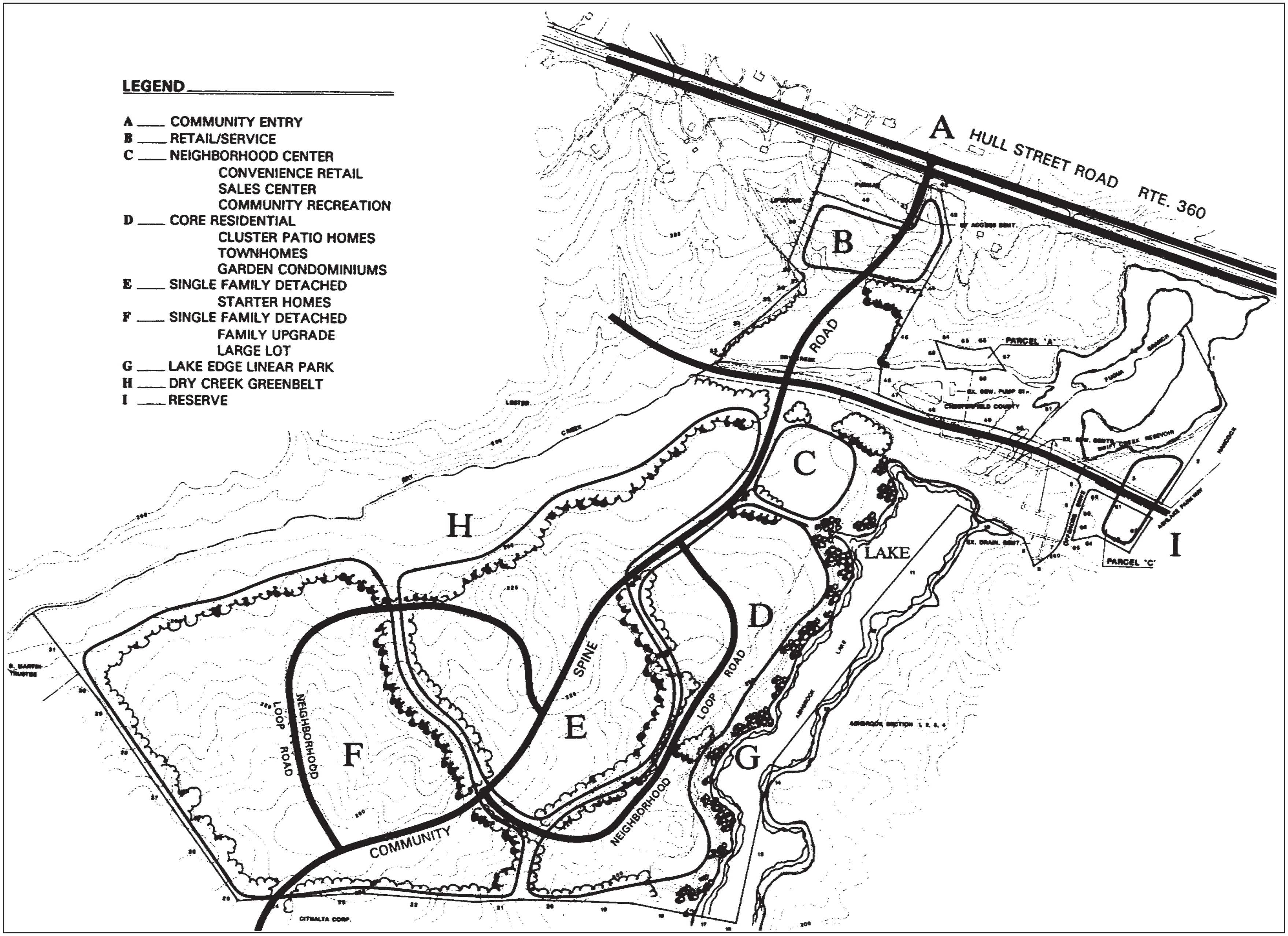

FIGURE III.1 Conceptual design.

CHAPTER 11

DEVELOPMENT PATTERNS AND PRINCIPLES

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Updated/Revised: N. Andrew Bishop LA, Planner

INTRODUCTION

The subdivision and development of land has long been an integral part of human culture and history. Humans have bound together to share resources, ideas, and culture, and provide each other with a mutual sense of security based on the premise of safety in numbers. In modern times people have bound together to create nodes, communities, cities, and economic centers motivated by a host of factors, from the basic needs of food, water, and shelter to more complex social dynamics including environmental, economic, cultural, and political considerations. As the populations of cities have grown in numbers and diversity, so have their physical size and composition. In the process, these cities take up more land, creating suburbs and secondary, or edge, cities of the original settlements. This chapter discusses the more recent development patterns and principles influencing the design of cities today and offers some general guidelines associated with their application.

The single most influential and guiding framework for any land development project is the context of the site and how it relates to the surrounding community and environment. Community in this sense is more than the physical characteristics of a site; it is the project's given sociocultural, political, and economic context, with which the site has a direct and indirect relationship. A development should blend with its surroundings to be successful and be sensitive to the urban, suburban, or rural context in which the site exists. The local context of a site often offers a guide to the project's design opportunities and constraints. Development considerations that are mindful of creating a sense of place or unique character can provide a new perspective from which the design flourishes. The (re)emergence of traditional neighborhood development (TNDs) and transit-oriented developments (TODs) has been relatively successful because they are examples of design patterns that seek to develop a distinct community personality. Similarly, projects associated with smart growth and green development practices offer meaningful insight into environmentally responsible land development practices, and are supported by many communities and review agencies because they are appropriate considerations for all types of development practices regardless of the project's size, density, or location—urban, suburban, or rural.

Architectural styles vary from one geographic region to the next, and it is these regional variations that help create a sense of place as well as establish a unique set of design characteristics. These variations are influenced by the local history, culture, and heritage of an area. These styles in turn affect the development patterns of an area in terms of density, aesthetics, and arrangement of uses. Due to these differences, a variety of names are often used to describe similar types of patterns and land use. A variety of factors determine the type, land use, and configuration of a development. Some of the more influential design and development factors are the landowner(s), community group(s), the availability of land, the cost of land and construction, the natural and environmental attributes of the site, the local zoning (or overlay district of a property), and the character of the surrounding community. These factors are often modified (sometimes to a great degree) by local regulations, which are based largely on the more encompassing issues of the health, safety, and welfare of the public. Local considerations relative to the nature of commerce, prevalent community attitude, and past community practice can also influence development and redevelopment projects.

Examination of a jurisdiction's zoning ordinance in all but the smallest communities reveals a great variety in the categories of permitted land uses. Typically, the zoning of a property is either residential, commercial (at times the use is specified as office or retail), open space, or industrial. Depending on the size, location, density, and maturity of the community, a jurisdiction's zoning document may establish other land use categories to reflect a unique economic base such as manufacturing, agriculture, maritime use, mining, forestry, or institutional use. Furthermore, the local jurisdiction's zoning ordinance (as described elsewhere in this book) normally identifies a series of development standards or minimum bulk requirements. The standards may include but are not limited to lot size; building height; front, rear, and side yard setbacks; and open space or impervious coverage. Additionally, supplemental land use ordinances, commonly a subdivision ordinance, may identify utility requirements, easement sizes, and location, as well as right-of-way and road widths. It is often necessary and very helpful to assemble the local specifications for a project in order to have a thorough understanding of any and all design constraints that may affect the conceptual layout.

If there is a common denominator throughout contemporary development practice, it might be the heavy reliance of today's society on the automobile. The suburban development pattern is often shaped and characterized by a strong dependence on the car for work, leisure, and day-to-day trips. Historically, the separate clustering of residential and employment or convenience centers into different areas has made public transportation infeasible for many communities. As a result, much of the population commutes by way of the single-occupant automobile, which continues to be the most prevalent form of transportation in the suburbs. This phenomenon places a unique set of requirements on all resulting land use types and development patterns. Attention to a common need for both vehicular circulation and on-site parking is necessary. Streets and roads provide the common linkage between and within land uses and the principal framework of the resulting development patterns. Similarly, parking requirements for the automobile are a major design element, often driving the size and organization of individual land uses. Many of the land use codes and ordinances support a vehicle-based design pattern; however, recent reports linking public health to the built environment (Ewing and Kreutzer, 2006) have resulted in renewed interest in and attention to the pedestrian components—sidewalks, trails, bike paths, and open space—of development.

DEVELOPMENT PATTERNS

Ideally, a community seeks to guide its growth in a manner consistent with its heritage, common goals, and economic interests. Local land use activity is often guided by a comprehensive or master planning process, which represents a variety of policies, priorities, and practices. Comprehensive plans for a region are usually subjected to extensive public participation, focusing on topics such as population and economic growth, housing, community facilities, traffic patterns, education, and the surrounding land uses. While a comprehensive plan may contain a mapped graphic representation of what the community might look like, the local zoning ordinance and zoning map are often the tools that provide the day-to-day implementation strategies to form the intended character of the community and direct land use decisions relative to the overall comprehensive plan objectives. A clear understanding of the distinction between these documents is imperative to understanding the land use patterns and development activity in a given community. Decision makers in land development and design must be sensitive to the rationale behind the comprehensive plan and guide the site's design accordingly while adhering to the design standards and criteria governing the size, form, character, and density of the proposed development, as identified in the local zoning ordinance or similar jurisdictional regulations.

Historically, zoning ordinances have relied on the delineation of distinct geographic zones or districts that accommodate a certain type of development. The land use types in these districts typically include residential, commercial, open space, and industrial classifications. Subcategories for each use may stipulate a range in density within the land use, prompting alternative development patterns or building programs. While much land development activity is single-zone or single-use development, other, more flexible development patterns exist in planned unit, transit-oriented, and mixed-use development zones. The objective of these types of developments is to move beyond the single-use zone and attempt to foster a framework for greater variety in the permitted land use arrangements. Prior to the discussion of individual land use types and specific development types, it is beneficial to briefly outline some of the broad planning types and terms.

Conventional Subdivision

Historically, the most common type of suburban development is the conventional subdivision. Created by the division of a larger land tract or parcel into smaller land units for both dwelling units and nonresidential spaces, such subdivision commonly requires new streets and utilities to service the newly created smaller lots. While subdivisions have become varied in pattern, lot size, street alignment, open-space network, and in some cases a mix of permitted land uses, conventional development continues to thrive on the simple premise of subdivision of land. It has been the mainstay of suburban residential development and accommodation of proximate retail, employment, and public facilities. The larger tract of acreage is divided in a manner that provides the complete transfer of land ownership to the subsequent users. Streets are normally incorporated into public ownership, and community open space, if provided, may be deeded to an appropriate public or semipublic entity. Single or multiple builders may, on a lot-by-lot basis, initiate construction. Figure 11.1 represents a typical conventional subdivision.

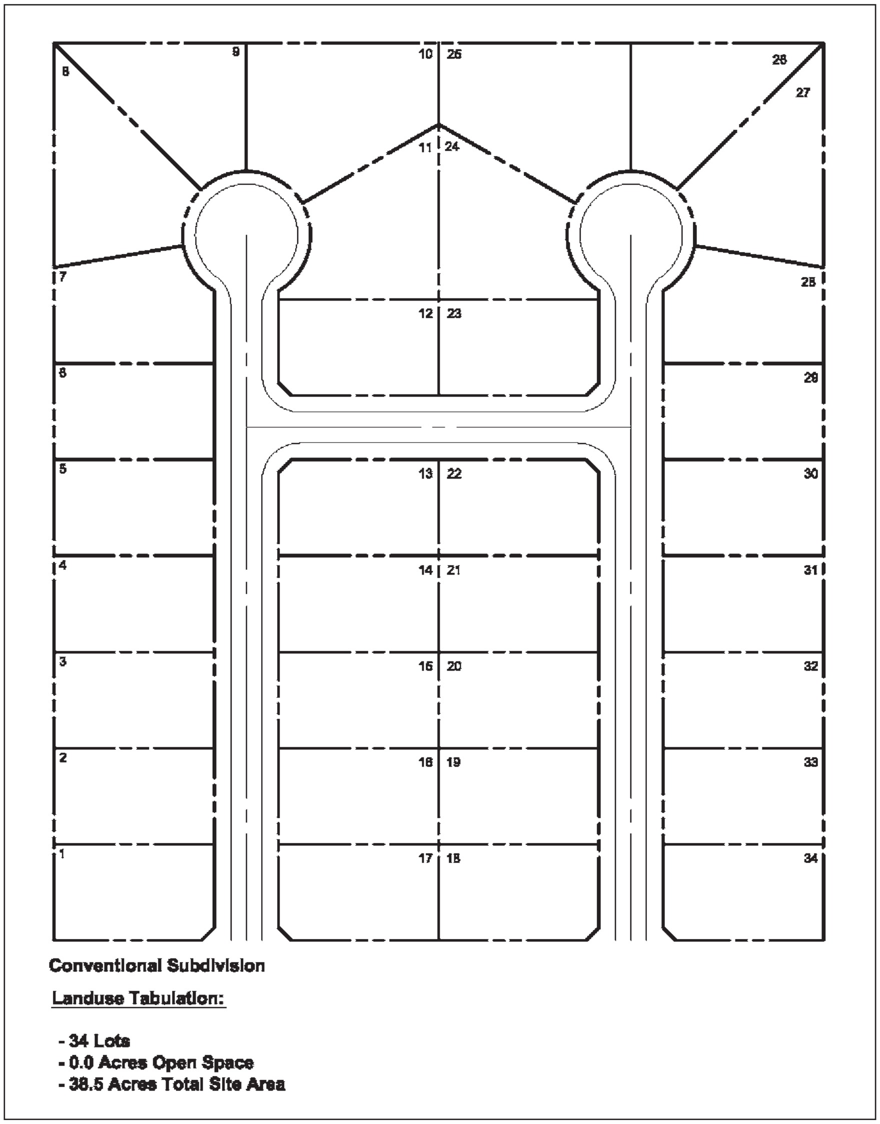

Figure 11.1 Typical conventional subdivision.

New Approaches to Subdivision: Providing Design Flexibility

In response to the real and perceived shortfalls of traditional design practices—namely, conventional subdivision development—several new approaches to residential subdivision have emerged. These modern-day approaches to subdivision seek to provide additional design and layout flexibility while achieving the same density otherwise permitted by traditional zoning and conventional subdivision. Often jurisdictions that allow alternative subdivision approaches (such as those discussed) require a concept plan for a conventional subdivision to determine the maximum feasible number of lots. Thus, if the conventional subdivision approach is applied to a 50-acre property and yields 25 residential lots, the maximum number of residential lots provided using any alternative subdivision methodology will often not exceed 25.

Alternative approaches to subdivision strike a balance between development demands and resource conservation. By providing the same density that would otherwise occupy the subdivision in a smaller or concentrated development footprint, these alternative approaches provide a unique forum for thoughtful design and distinct advantages in terms of optimizing the development potential of the land. These alternative subdivision planning concepts aim to:

- Enhance conservation/preservation of environmentally sensitive areas
- Provide economic diversity within individual development projects
- Reduce infrastructure costs by utilizing compact or concentrated layout patterns

- Increase the linkages and connectivity between neighborhood entities and subdivisions
- Yield economic value from land dedicated to agricultural or other natural resource production endeavors without obliterating said use

Cluster Subdivision. Cluster subdivision relies on subdividing larger properties into smaller lots or parcels, but differs from conventional subdivision in that it typically results in a land plan with a greater percentage of the overall acreage set aside in common, conservation area, or open space. To achieve this type of development, the reviewing agency will generally allow a reasonable reduction in minimum lot size and setbacks, provided there is no increase in the overall number of lots that would otherwise be permitted under regulations for a conventional subdivision. Land that is not part of the residential lots is set aside as community gathering space or open space. A cluster subdivision commonly places the development on the most usable areas of a site, resulting in the reduction of development costs relating to site grading and infrastructure development and the preservation of or reduced impact on environmentally sensitive areas. Cluster subdivisions require increased attention to the details of the design and layout; for instance, the inherently smaller lots in a cluster subdivision necessitate alternate methods for privacy between adjacent units. As a result, greater controls are often placed on the individual unit design and orientation. A typical cluster subdivision is shown in Figure 11.2.

Lot Size Averaging. This planning concept takes the cluster subdivision one step further in terms of providing additional flexibility in lot size stipulations. Lot size averaging requires each lot to be equal to or greater than a specified minimum lot size and provides a minimum average lot size for the overall subdivision. For instance, a relatively rural community might specify that lot size averaging for a mod-

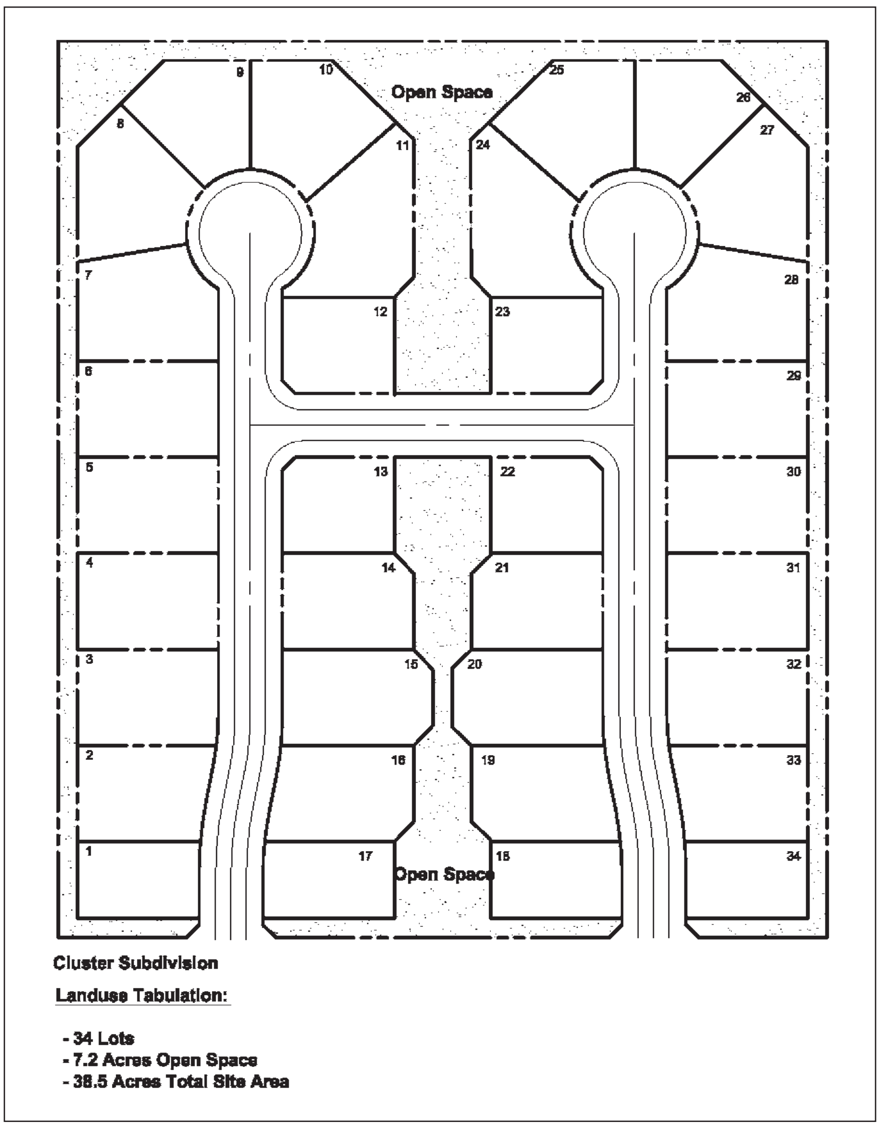

FIGURE 11.2 Cluster subdivision.

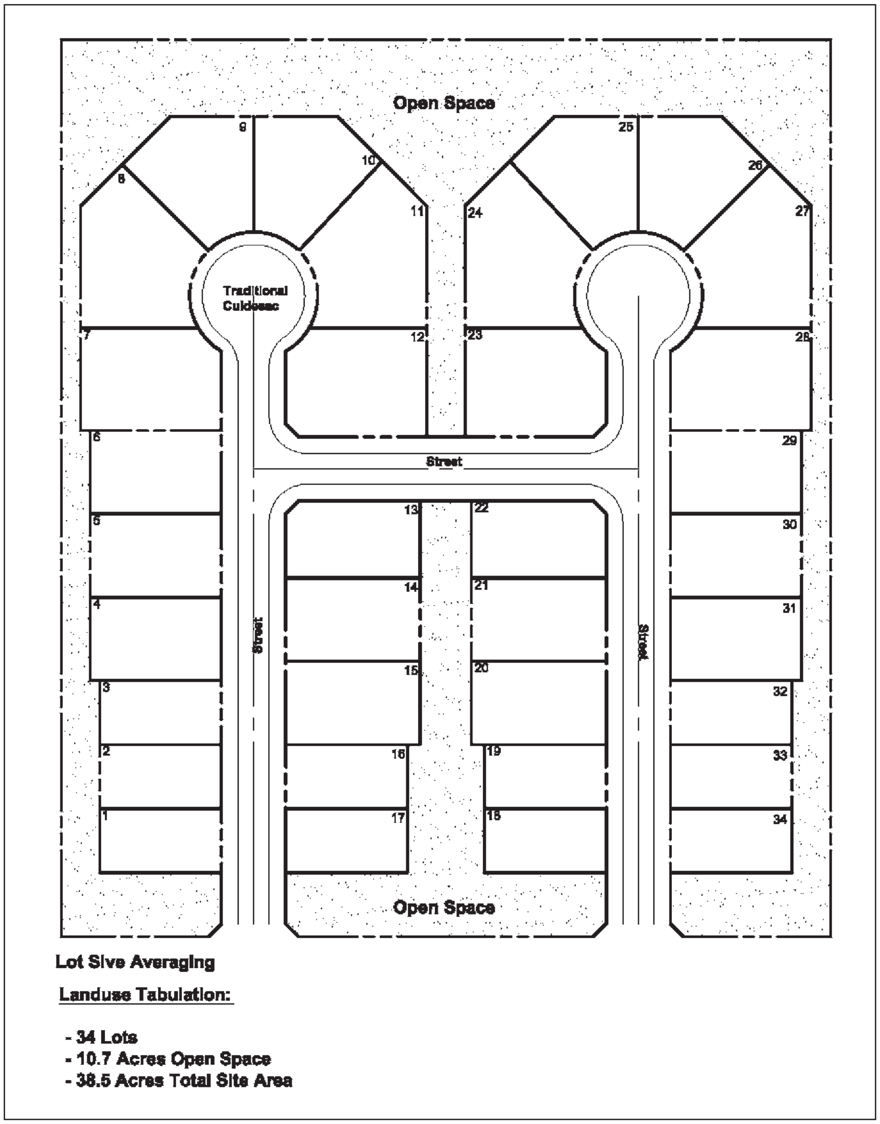

FIGURE 11.3 Lot size averaging approach to subdivision.

erately dense residential community shall provide lots with a minimum lot size of 3.5 acres; however, the overall *average* lot size of the community should be at least 6 acres. This methodology can be applied to any-size parcel subject to subdivision and results in a variety of parcel sizes within a single neighborhood/community. This approach is intended to provide a greater amount of design flexibility to enhance preservation/conservation efforts, minimize infrastructure costs, and enhance economic diversity (by providing a range of price points) within a single neighborhood. (See Figure 11.3.)

Conservation Subdivision. A conservation subdivision is an extension of the cluster concept; it is similar in many of its characteristics including a reduced lot size and commitment to preserve open space, but it is more common in rural and greenfield applications and almost always includes a significant portion of the land placed in perpetual conservation via easements, agreements, covenants, or other legal restrictions. (See Figure 11.4.) The allowable density is based on the underlying zoning and is achieved through significant lot size reductions granted in exchange for permanent preservation of sensitive environmental space, unique landscape features, productive land (agriculture or forest), or land with historical relevance. This open space is ideally part of a larger open-space system or green corridor. The land that is set aside as open space could be composed of wetlands, steep slopes, or other environmentally sensitive features that are more costly to develop in terms of site grading, infrastructure, and permitting.

Traditional Neighborhood Design (TND)

Traditional neighborhood design (sometimes referred to as *new urbanism* or *neotraditional* design) is derived from the contemporary design of the early to mid-1900s. During that period of time many cities in America were composed of close-knit communities, defined by usable green space, a

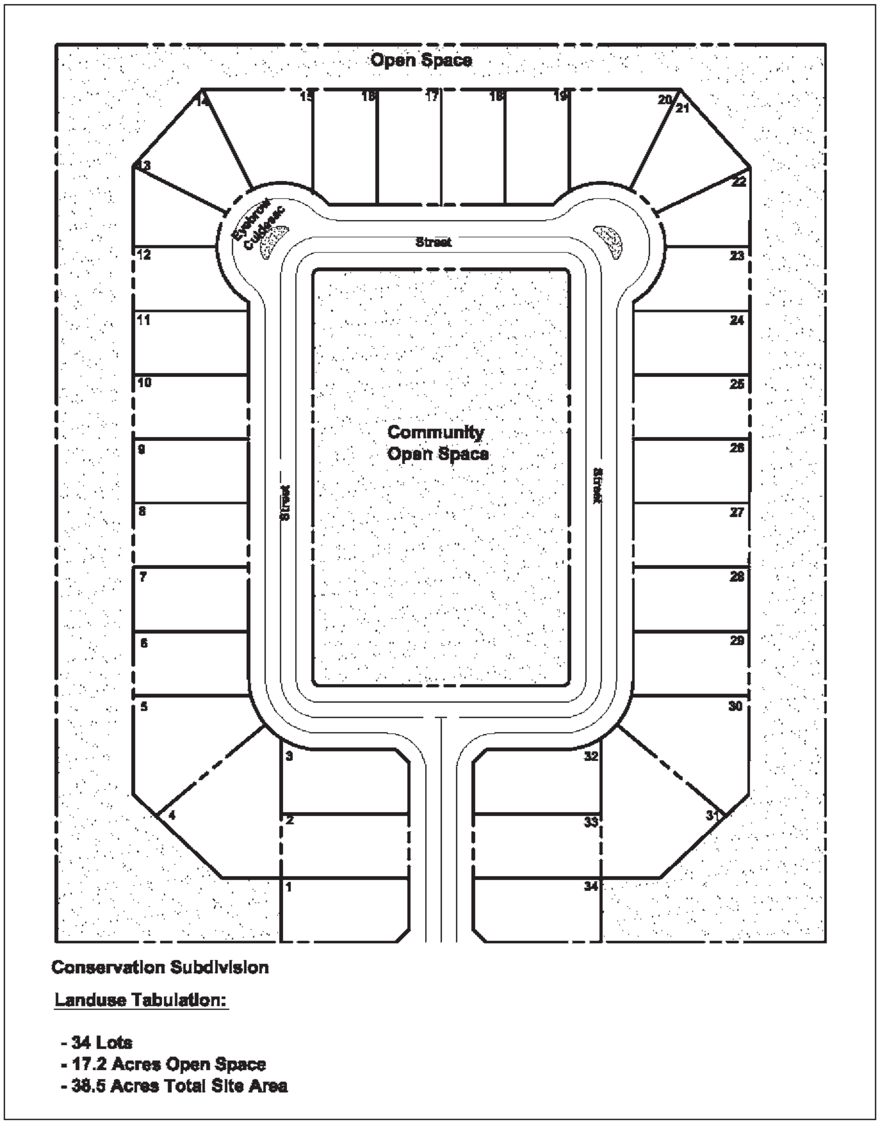

FIGURE 11.4 Conservation subdivision.

variety of housing types, and active streetfronts. TND seeks to recreate this communal experience through application of specific design characteristics at the lot, block, and neighborhood level. (See Figure 11.5.) TND neighborhoods are characterized by smaller lots and rear- (or alley-) loaded homes thus emphasizing the houses and the streetscape rather than parked vehicles. Many homes include front porches—an extension of the house itself—facilitating social interaction and lively street life. Traffic patterns throughout the community typically follow a modified grid pattern, with primary, secondary, and minor transportation corridors. These corridors allow for efficient automobile traffic and promote pedestrian activity. Streets may have on-street parking and when they do, ample space is typically provided between the street and sidewalk to create a green buffer, planting strip, or utility corridor.

These communities often include a commercial component and a central gathering space. The inclusion of a central gathering space, pocket parks, and other public open spaces scattered throughout the community creates distinct nodes in the organization pattern that facilitate pedestrian activity and a sense of connectedness. TND development can occur in both infill and greenfield projects. These types of developments are often driven by community interest, involvement, and economics, as they can result in a variety of housing types and price points within a single community. Through the use of TND developments, designers and decision-making bodies hope to accomplish a broad range of goals, including:

- Revitalizing the urban and suburban landscape through creation of livable, efficient communities
- Reducing suburban sprawl
- Preserving greenways and providing density in rural or fringe greenfield developments

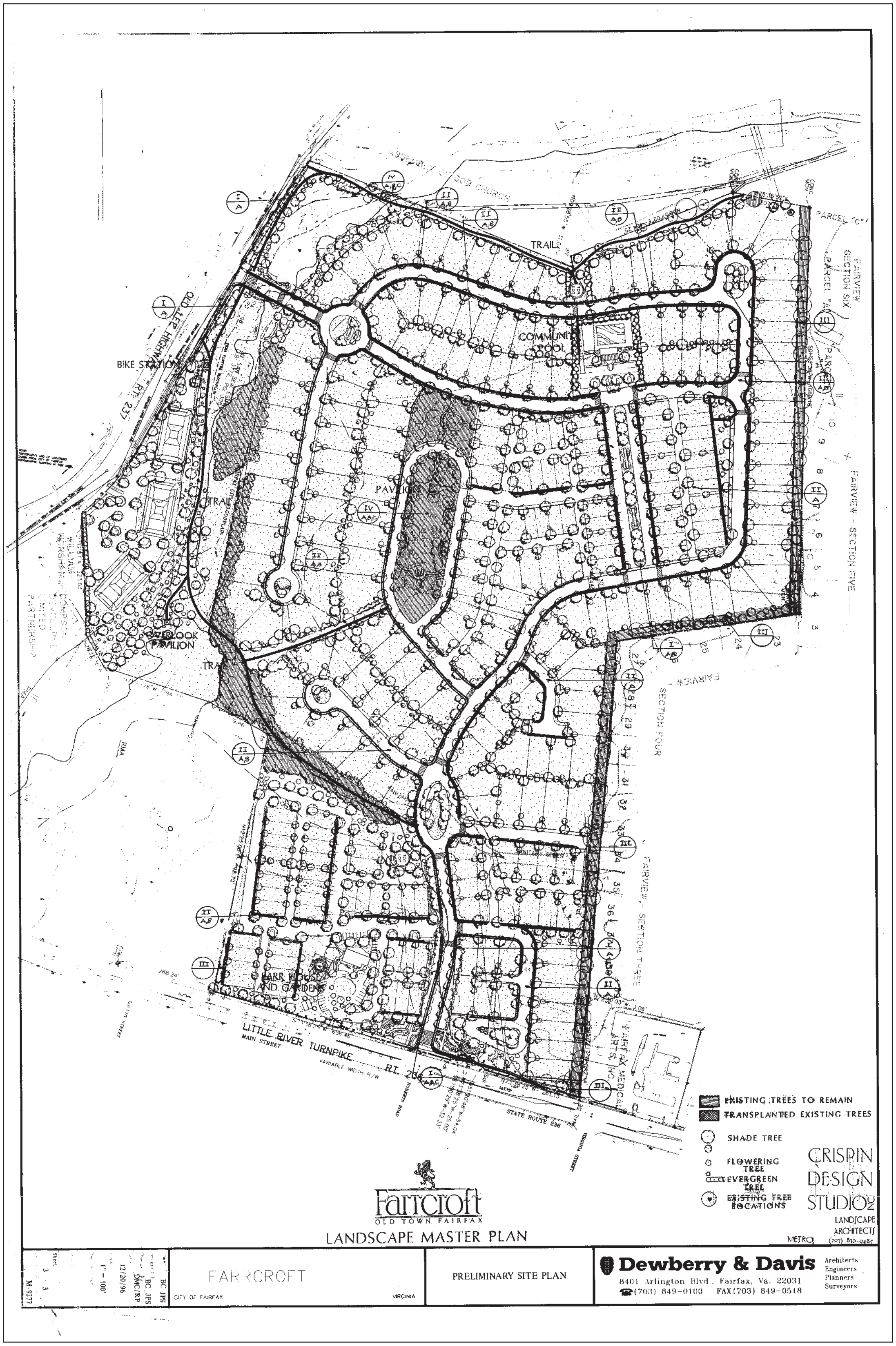

FIGURE 11.5 Neotraditional community plan.

- Improving the quality of life for those who live in or near these communities
- Reducing the dependence on the automobile as the primary source of transportation

Transit-Oriented Development (TOD)

Transit-oriented developments have emerged recently in many urban and suburban areas in response to extreme traffic congestion. Communities have begun to focus development around mass transit hubs, such as rail or subway stations, airports, bus terminals, or some other type of transportation corridor. Often the development density tapers from its highest point around the hub, decreasing as the development radiates out. These developments provide an alternative means of transportation, other than the single-occupant automobile. The developments are commonly composed of a variety of uses including residential, commercial, office, retail, and community open space. TODs focus on creating pedestrian-friendly environments, where the use of mass transit systems is encouraged. A development may be considered transit-oriented if it is within a half mile or approximately 10 minutes' walking distance of the transit hub. Goals of a TOD might include:

- Reducing traffic congestion and encouraging the use of mass transit or pedestrian forms of transportation
- Revitalizing urban settings, as metropolitan areas tend to have established transit systems, and reducing suburban sprawl by concentrating development at transit hubs
- Improving the quality of life for those who live in or near these communities by providing a safe environment that also meets lifestyle needs
- Reducing the dependence on the automobile as the primary source of transportation

Please refer to the color insert for a representative example of a transit-oriented development plan.

Active Adult Communities (age 55 and older)

Active adult communities are currently one of the fastest-growing development types in the building industry today. This type of development has evolved in response to the changing needs and desires of the baby boomer generation. Many of the individuals in this age group have matured and retired from their professional careers, and are ready to enjoy their golden years. These people often lead busy lifestyles—traveling, exercising, and playing active roles in their communities. Active adult communities are designed around the lifestyles of this targeted age group and their needs. They often offer a variety of resort-style recreational activities that may include golf course packages, country clubs, community fitness centers, spas, tennis courts, and nature or hiker/biker trails, as well as a host of other amenities. These types of communities may be private or gated, offering users luxury, convenience, and value unmatched in other developments. The product types available in these communities include single-family homes, townhomes, condominiums, and villas. A number of active adult communities are designed to offer homes where residents can relax and enjoy a carefree lifestyle. The units are often designed with the master bedroom on the first floor and provide lots that are typically smaller than those found in many conventional subdivisions, thus reducing homeowner maintenance responsibilities—a desirable perk for this age group. Maintenance packages for individual properties are often offered through the community homeowners' association. A major factor in the success of these communities has been the impact, or lack thereof, on the local education systems. An active adult community provides a tax base to the local government but does not place any stress on a local school system because these communities are designed for people age 55 and older, not families with children.

Please refer to the color insert for a representative example of an active adult community plan.

Mixed-Use Development

Mixed-use developments, sometimes called MXT developments, are becoming increasingly popular in both urban and suburban areas. These types of developments do just what their name suggests: they provide a mix of uses on a given parcel(s) of land. They create nodes or places of interest and should ideally be placed along or proximal to transportation or other high-activity/visibility corridors. These corridors are not limited to just automobile corridors, but may include systems of mass transit, pedestrian connections, or greenways. Creating nodes within the community provides it with a sense of organization and facilitates the traffic patterns—pedestrian, vehicular, or otherwise—between nodes. By combining uses, the development becomes a vibrant area where citizens can live, work, and recreate (play) without having to travel between each activity. Beyond the mix of uses, signature design elements include the streetscape and scattered open-space areas, usually in the form of pocket parks or plazas. Buildings are often organized with retail or office space located along the first floor, with residential units or additional commercial space above. MXT developments are typically dense and use unit types such as townhomes, condominiums, and multifamily products.

Please refer to the color insert for a representative example of a mixed-use development plan.

Master Planned Communities

Master planned communities are typically designed as a single comprehensive entity on a larger tract of land. Master planned communities generally provide a mix of unit types and land uses, both public and private. The unit types might include townhomes, condominiums, villas, varying sizes of single-family homes, and commercial, retail, or possibly industrial or institutional components. Ideally, this planning method creates a balanced hierarchical community. The development is often connected by an open-space network, transportation system, or some other type of organizational feature. Amenities in these communities vary and might include unique environmental features, a golf course or other recreational function, an open-space or trail system, or a destination location such as a town center, community green, municipal building, neighborhood attraction, or regional commercial center. A planned community represents a large land assembly that attempts to satisfy a full range of lifestyle choices and provides the requisite support elements to sustain its resident population. Normally, development is undertaken by a single owner or master developer who, in addition to orchestrating the financing, planning, and design of a project, may construct the required infrastructure and community amenities, making sites available to others for individual building construction.

Please refer to the color insert for a representative example of a planned community.

DEVELOPMENT PRINCIPLES

When developing a potential site, the design team must consider the effect that each type of land use has on the environmental, aesthetic, financial, operational, and marketing characteristics of a project. They should understand the relationship between these characteristics and their effects on adjacent properties and the community as a whole. The effects may range from the physical limitations a development has on its immediate site to the community's predisposition to a proposed development and its program. Following are some characteristics that warrant consideration because of their implications on resulting land use patterns. Generally, there is a direct relationship between the intensity and density of development and its impact on the site and surrounding community. These concerns may focus on the following topics.

Environmental Impacts and Opportunities

Site Disturbance. More clearing and grading are required as buildings, site improvements, and infrastructure occupy an increasing proportion of land. There is normally a reduction in the opportunity to retain natural grade as density increases. Opportunities to preserve existing wooded or other natural areas are similarly reduced as building program coverage is expanded. Lower building density does not in itself result in lower impact. It is the combination of existing conditions, proposed program, and resolution of program detail that eventually delineates the degree of impact. An equivalent program in a more compact development envelope can have substantially less site disturbance impact than a comparably sized program dispersed over a greater amount of acreage. Similarly, building programs, which are tailored to unique site conditions, can have less impact on land than generic solutions. For example, a residence designed for a steep site will be a better fit and require less grading than one originally designed for level terrain.

Stormwater Management. As the impervious surface associated with a given development program increases, so does stormwater runoff, along with the increased potential for non-point-source pollutants. Depending on the jurisdiction's stormwater management regulations, there are a variety of options employed to collect, treat, and detain/retain runoff efficiently; structural controls are space efficient but tend to be more costly whereas natural measures tend to consume more space but are generally cheaper to construct. Higher density can assist in financially compensating for construction costs associated with more expensive mitigation measures.

Green Development. Green development (also called *sustainable* or *low-impact development*) is a term that is used loosely by local organizations and public groups to describe environmentally sensitive development characterized by informed site selection, energy-efficient design and construction, mindful material selection, and waste reduction. These types of development practices might include green roofs; xeriscaping; passive heating; solar, thermal, or wind power; water conservation strategies including cisterns or rain barrels with reuse applications; or some combination thereof. All of these practices strive to achieve a similar goal: to create an environmentally sensitive and sustainable community. The U.S. Green Building Council's LEED rating systems are the most prevalent measure of sustainability. During the conceptual design phase, decisions regarding street, lot, and building layout—effectively, the development pattern—can greatly influence the overall energy efficiency of the building(s) and the development as a whole. Passive heating and cooling design is highly dependent on proper building orientation (see Figure 11.6). The designer should utilize the results of the feasibility study and site analysis—in particular, the climate and microclimate analysis—to site or lay out the infrastructure and orient buildings.

Aesthetic Impacts and Opportunities

Context. Compatibility with adjoining land uses can become problematic as proposed development intensity increases. Careful site planning and design can assist in mitigating this problem. Structural solutions may be costly, and buffering solutions may be land consumptive.

Architectural Design. More intense development generally requires more stringent architectural controls to ensure overall visual coherence. Modest building elements on large lots or parcels benefit from distance between improvements. Individual units capture their own identity and are less visually and functionally dependent on their neighbor. As building size increases or as parcel size decreases, increased proximity warrants greater attention to issues of compatibility.

External Views. Larger buildings or more intense building programs may impact the extent and quality of exterior views. More dense development requires careful site planning to ensure privacy and minimize the visual and noise impact of abutting uses.

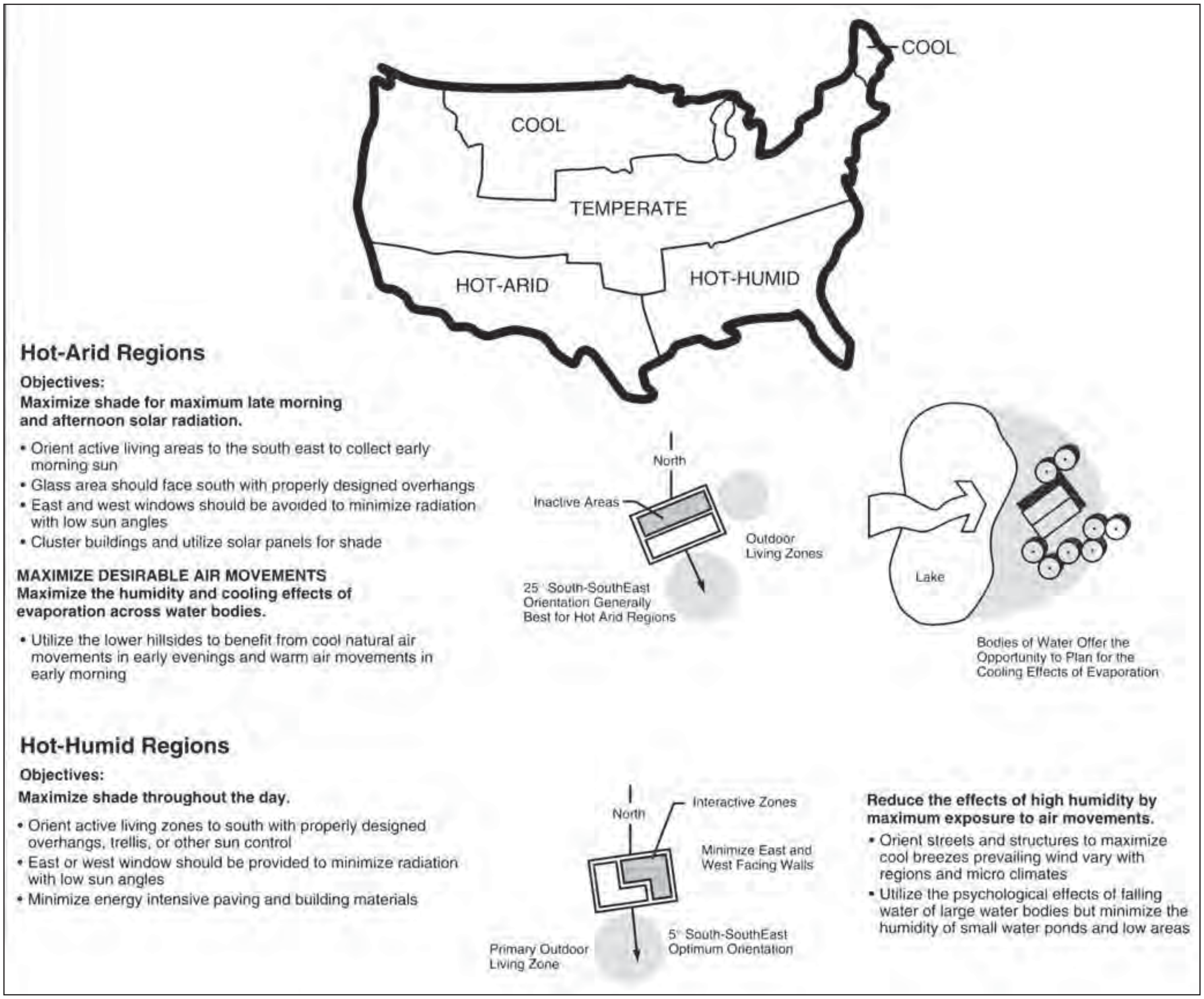

FIGURE 11.6 Considerations for siting a building for different climate regions of the United States. (Courtesy Robinette, Gary O., and Charles McClennon. 1983. *Landscape Planning for Energy Conservation.* New York: Van Nostrand Reinhold.

Financial Impacts and Opportunities

There are many ways to develop a property in a financial and environmentally responsible manner. While higher-density development may require greater total infrastructure costs, depending on the condition and capacity of existing facilities, it may also result in lower construction, operation, and service costs on a per-unit or square-foot basis. Developing properties at a higher density permits land costs to be distributed across a larger development program, resulting in lower per-unit land costs. In terms of the tax benefits associated with development, tax revenues generally increase on an acreage basis as a result of public and structural improvement; increased density normally results in a higher average per-acre assessed value, benefiting both the homeowner and the municipalities that tax the value associated with the home.

Operational Impacts and Opportunities

Maintenance. Occupants realize lower per-unit maintenance costs due to economies of scale associated with larger, more intense development patterns.

Energy. Per-unit energy cost savings are generally realized in development that is more compact.

Marketing Impacts and Opportunities

Market Exposure. Increased scale, intensity, or quality of development may foster a visual presence, which translates into greater market exposure. Depending on the actual development program, this may increase project appeal to a broader spectrum of the market or provide increased awareness among targeted consumer groups.

Community Identity. Larger-scale developments can provide additional justification for amenities, which may, in turn, increase community identity and resident/tenant affinity with a project.

RESIDENTIAL LAND USE

Typically, housing is the most prevalent land use within a jurisdiction. Residential design requires sensitivity to the pragmatics associated with construction economics, an understanding of site conditions, and an appreciation for consumer lifestyle preferences. Similarly, sound residential planning and design require a genuine appreciation for the individual dwelling unit and how it functions. To understand unit function and, consequently, efficient layout and development, certain relationships must be clarified, including such considerations as the number of doors and windows and their relationship to exterior grade, the feasibility of steps, and homeowner desires for certain add-ons such as a deck, porch, fireplace, or future extension. These considerations are important in terms of the horizontal and vertical layout of the site. Additional detail on the consequences of these considerations on vertical design (grading) is included in Chapter 23.

Single-Family Detached Dwellings

In a single-family detached residential dwelling, each individual living unit is a freestanding structure. Each dwelling unit normally occupies a separate recorded lot. In a conventional lot arrangement, the single-family home is surrounded on all sides by property or yards reserved for the occupant's exclusive use. The lot must meet a minimum or average size prescribed in the community's zoning ordinance. Figure 11.7 is representative of a typical conventional subdivision lot, and Figure 11.8 represents a cluster subdivision lot. Both lots are shown to illustrate the reduction in bulk requirements typically seen in cluster zoning.

Utilization of cluster lots requires greater attention to house siting and house-to-house relationships, given the need to maintain community design standards among smaller average lot sizes. The benefit of cluster development rests with the potential reduction in per-unit infrastructure costs, given the aggregation of dwellings on only a portion of the project acreage. Similarly, the conservation of community open space in cluster arrangements and its amenity appeal may offset market concerns with smaller lot sizes and the potential reduction in individual unit privacy. Conventional or cluster arrangements alone do not dictate lot size. Relatively speaking, large and small house types may be developed in either arrangement. While acre and multiple-acre home sites are common in suburban areas, more typical single-family detached lots range from ¼ to ⅓ acre in size. However, current trends are moving toward smaller lot sizes, given escalating land costs and changing lifestyle requirements. Single-family detached dwellings on 2000- to 5000-square-foot lots are increasingly common in both infill developments and planned communities.

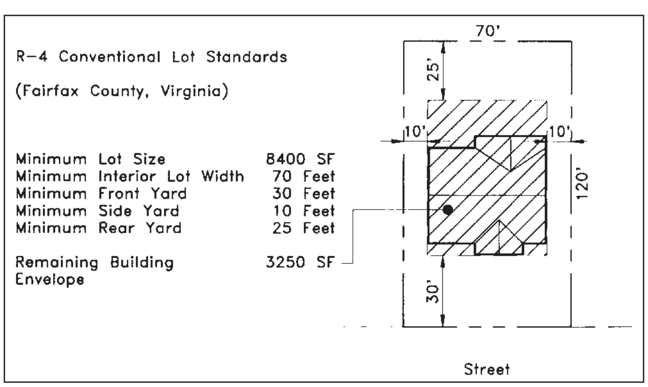

FIGURE 11.7 Typical conventional lot.

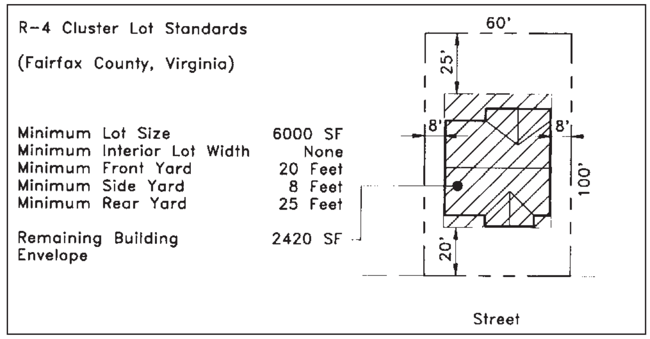

FIGURE 11.8 Typical cluster lot.

Lots are normally square or slightly rectangular in shape. Minimum lot widths are generally governed by local zoning ordinance. Decisions to exceed that dimension are often prompted by market demand for additional distance between dwelling units, the dimensions of the proposed house, or preferred driveway approach to the garage. An attached side-loaded garage requires a wider lot than a similarly sized front-loaded facility.

Lot lines normally run perpendicular to the street frontage. Variations in lot configuration commonly include pie-shaped lots around cul-de-sacs and flag or pipestem lots. The latter convention provides limited lot width along the public street frontage to accommodate driveway access and a widening of the lot at the building setback line sufficient to satisfy the desired house type and its yard requirements. Examples of these lot configurations are presented in Figure 11.9.

Pipestem or flag lots were originally designed to allow access to otherwise landlocked parcel acreage. Use of this technique recognizes the environmental and economic advantage in substituting private driveway lengths to tap land that otherwise would require additional street length and potentially greater site disturbance and infrastructure costs. The negative attributes of this technique include the potential burden on homeowners to individually maintain longer driveways or private street lengths, potential access constraints for emergency vehicles, and possible undesirable house-to-house relationships, as pipestem dwellings may be perceived to be in the rear yards of adjacent residences. However, judicious use of the pipestem lot arrangement can pose distinct benefits in residential design when its use,

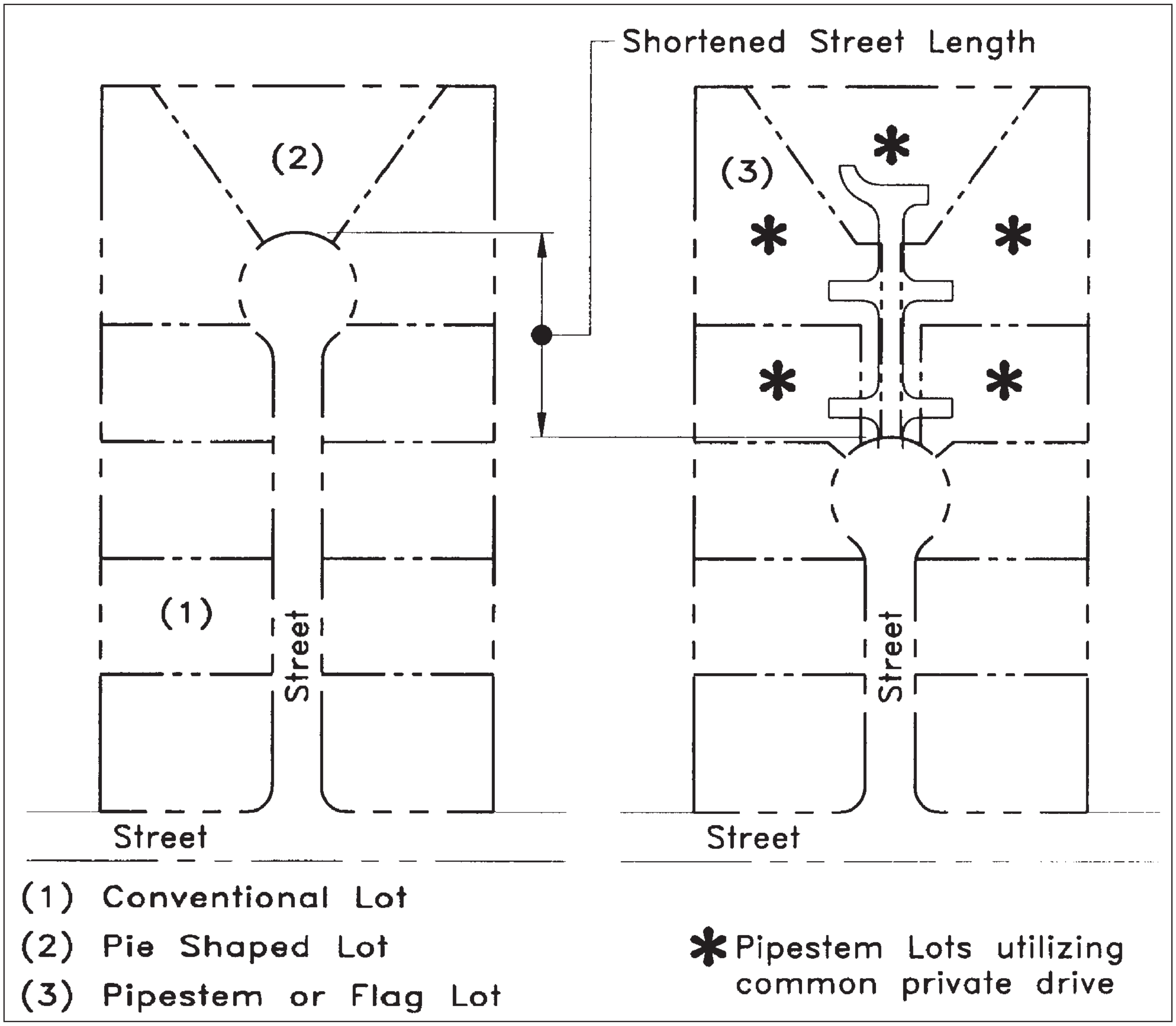

FIGURE 11.9 Example of conventional lot, pie-shaped lot, and flag or pipestem lot.

resulting lot size, dwelling orientation, and access considerations are based on sound site planning and community design criteria.

Zoning ordinances generally provide setback and yard requirements for single-family residential development to ensure functional side, rear, and front yards. Front-yard setbacks are generally a minimum of 20 to 30 feet to accommodate the length of a parked vehicle in the driveway. Front-yard setbacks may vary depending on the nature and scale of the adjacent street. Lesser setbacks may be acceptable where alternative parking arrangements are provided, as is the case where rear-accessed alleys or service drives are employed. Deeper setbacks may be required along more heavily traveled arterial streets than on neighborhood streets or cul-de-sacs with less traffic volume. (See Figure 11.10.)

Demand for affordable single-family detached housing in a time of escalating land prices has prompted greater reliance on smaller lots. The smaller lot size not only appeals to builders and developers who can realize lower per-unit infrastructure costs and higher per-acre unit yields but responds to consumer preference for the reduced maintenance requirements associated with the smaller yards. Smaller lots, in well-designed communities with provisions for common amenities, appeal to a lifestyle that seeks convenient accessibility to diverse leisure activities. Safeguards to a well-designed small-lot community reside in well-conceived architectural design of the unit and sensitive site planning.

Design Considerations

While conventional subdivision regulations normally prescribe setbacks for front, rear, and side yards, dwelling unit design, variation in lot sizes, lot dimensions, and concessions suited to cluster or unique detached housing prototypes provide opportunities to tailor design to local market

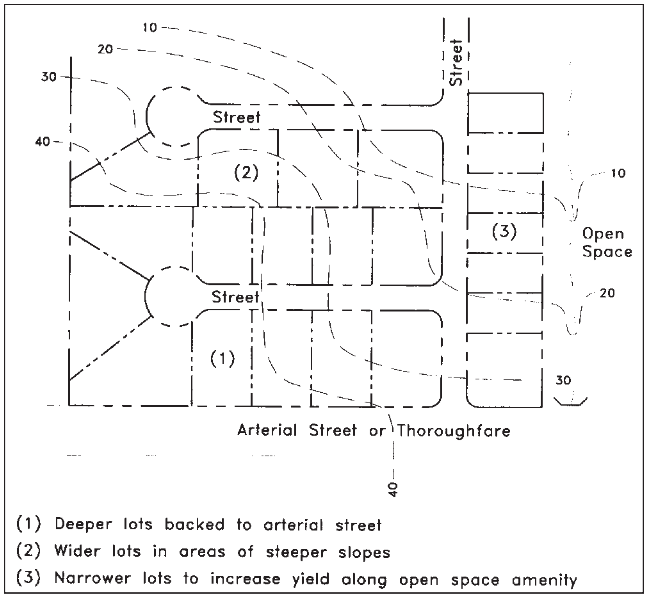

Figure 11.10 Example of variation in lot size due to site characteristics.

and site conditions. Several groundrules can provide a strong foundation for residential layout design:

- Lot and place houses in a manner that responds to the site's natural features.
- Avoid extremes in either random plan organization or uniformity to the point of monotony in the pattern of development.
- Establish appropriate block lengths to minimize long views of repetitive house fronts, garages, and driveways as well as to foster convenient vehicular and pedestrian movement.
- Ensure yard dimensions and unit orientation that promote individual dwelling legibility and sufficient yard privacy.
- Establish a sense of place through a coherent and legible circulation system.
- Reinforce the street hierarchy through practical application of building setbacks.

Single-Family Semidetached Dwellings

The single-family semidetached dwelling, commonly referred to as a duplex unit, consists of two living units that occupy a single structure, separated by a common wall. Each dwelling has its own exterior entrance and is located on a separate recorded lot. Each dwelling unit is surrounded on three sides by property reserved for the occupant's exclusive use.

Single-Family Attached Dwellings

Single-family attached dwellings include housing types with multiple dwellings in a building arrangement where two or more dwellings share common walls and, in some cases, common floors and ceilings. Each unit has a separate private entrance at grade level and usually a contiguous exterior yard reserved for the occupant's exclusive use. Variations may include the following.

Town House (Row House or Townhome). Comprising three or more units attached side by side, the town house, long a common urban housing prototype, has become a popular component of the suburban housing market. A common or party wall separates individual units, each with an at-grade entry. Property on at least two sides, normally front and back, is generally reserved for the occupants' exclusive use.

The town house provides flexibility in plan and style, with design variations that include integral or detached garages. Indoor/outdoor relationships generally focus on the rear yards, although they may orient to small front courtyards. Exterior yard privacy may be enhanced with landscaping, fencing, or privacy walls. Lot widths can vary depending on the desired character of the unit. While conventional suburban townhomes may range from 16 feet to 24 feet wide; units of 32 feet or greater are not uncommon when market considerations warrant a street presence approaching that of a single-family detached residence. At the more conservative widths, lot depths may range from 60 to 100 feet. Densities normally range from 7 to 12 units per acre. Depending on the unit width, parking requirements, site conditions, and desired community character, densities of up to 20 units per acre are not uncommon in more urban settings. Figure 11.11 illustrates a range in town house configuration including the more conventional front-loaded unit, courtyard, or clustered town house court, and alley-served units.

Each town house dwelling has a separate front door, although end units may have side entrances. Generally, each house has its own utility connections. Typically, local ordinances prescribe the maximum number of side-by-side units that may be aggregated into a single town house "stick," or building group. While sticks of six to eight town houses have been a common development practice, combinations of three to four units, comparable in scale to a large single-family residence, are popular in some high-end market segments.

Building lengths with more than eight attached units are more commonly found with narrow, 18-foot or less average unit widths. Shorter lengths, and a higher percentage of end units, are generally associated with wider, upscale townhomes or in instances where parcel dimensions preclude longer lengths.

While the urban town house was configured in a linear arrangement (see Figure 11.12), with units oriented to the street, the suburban town house community has sometimes taken on a more organic, less geometric, arrangement. This has occurred in response to site conditions, which have accommodated a more expansive layout, as well as a proclivity toward arrangements in which the unit's front faces

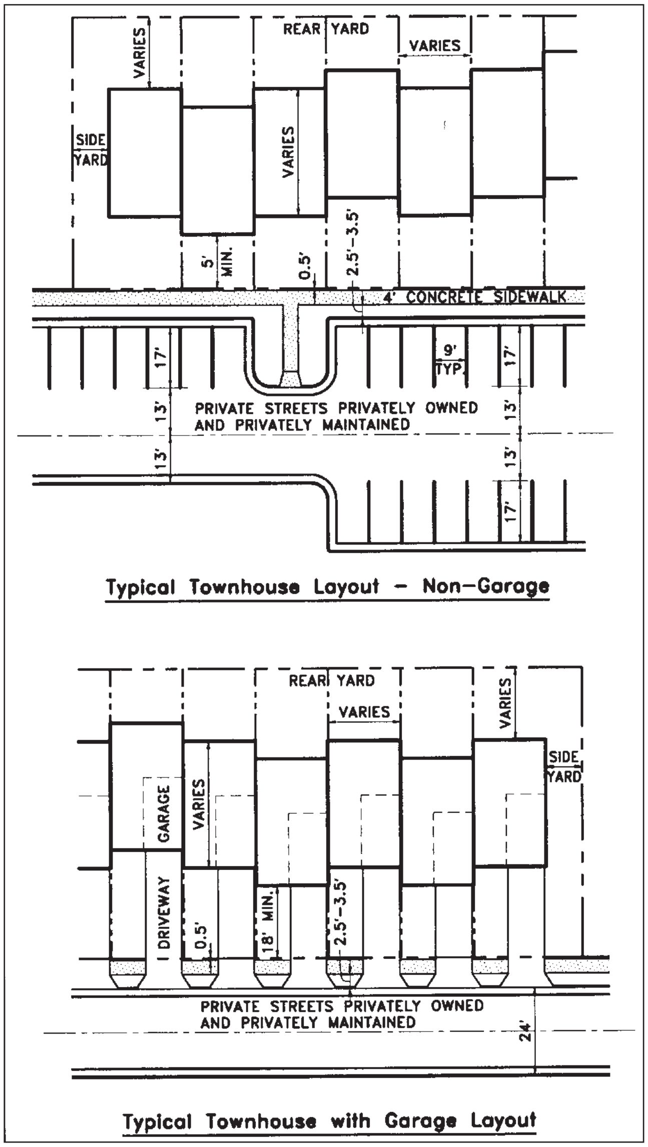

FIGURE 11.11 Typical town house condition.

toward the parking lots and at the rear are open-space amenities. The urban street setting with its attendant parallel parking and supplemental rear service alley access had been preempted, in the suburbs, by the front service drive and its associated perpendicular parking. Variations do include town house layouts that focus on a court and mew arrangement of units acting as small personal open spaces for these units. The former generally results in a cluster of townhomes fronting on a common parking area often referred to as a parking court or parking bay. The common vehicular circulation area serves as the organizer for the cluster. The mews arrangement focuses on a pedestrian open space to organize the front facades of the individual townhomes, with parking at the terminus of the pedestrian area or at the rear or underside of the units.

Back-to-Back Town House. While considered an attached multifamily housing type in many jurisdictions, the back-to-back town house often divides the length of a traditional town house stick with an additional common wall that serves to separate units organized along opposing facades. The resulting aggregate building form has two front yards. The double frontage prompts a need for careful site planning to ensure the convenient placement of adequate parking for each unit. Reliance on a single exterior exposure for each residence requires subtle design considerations to balance the semipublic nature of a front entry with any privacy requirements associated with the singular exterior living space, which occupies the same facade. (See Figure 11.13.)

Other Town House Variations. Another variation to the townhouse is the stacked, or piggyback, town house. This may include a multistory town house unit over a single-story flat or a multistory town house over a similar multistory unit. Such arrangements work well on sites where topographic change allows upper and lower units to be accessed at grade on opposing sides of a building. In extreme instances the lower unit may be reduced to a single exterior exposure.

Alternating town houses with stacked flats in the same building can produce additional diversity. The flats, sometimes referred to as *coach homes,* may be located either at building ends or in interior locations. This arrangement is often classified as a multifamily residential product subject to zoning requirements and accessibility requirements associated with that use category. Figures 11.14 and 11.15 illustrate the combined town house/coach house and piggyback/stacked town house, respectively.

Multiplex. Used with a prefix representing the number of attached units, such as duplex, triplex, or quadraplex, multiplex residences consist of two or more units in various configurations, each with its own separate at-grade exterior entrance. Piggyback town houses and manor houses are often considered multiplex units. The yards surrounding a typical multiplex unit may be reserved for common occupant use or portions of the yards may be designated for an individual unit's exclusive use. Figure 11.16 shows a variety of multiplex combinations.

As the number of units in this type of attached residential arrangement increases, unique opportunities and constraints in both design and construction are posed. Unit design, solar orientation, indoor/outdoor relationships, privacy provisions, convenience of automobile access, and parking must be weighed against the increase in density and reduction in per-unit land, construction, and infrastructure costs.

Live/Work Units

Live/work units often occur in a more urban environment and are typically composed of a multilevel structure similar in nature to a townhome or duplex, where the first floor is the retail or office component and the subsequent floors form a residential unit. The live/work scenario presents a unique architectural challenge as the facade is both a storefront and a house front. This may include two separate entrances, unique window treatments, signing considerations, and parking considerations. Live/work units would typically be parked at the residential rate, as it is generally assumed that the work component is a community-serving establishment and as such would not have high vehicle demand. These types of units are often seen in mixed-use, transit-oriented, and neotraditional development patterns. Live/work units can create a unique sense of place and provide a community with a greater diversity in product type.

Multifamily Residential Structures

Multifamily structures are characterized by four or more units in a single building, with units sharing access to the exterior by one or more common entrances. Structures may be one or more stories, and multifamily communities or developments may consist of one or more buildings on a single tract or lot. Structures are surrounded by common open space, which often contains on-site recreational facilities for resident use. Private drives or service roads provide access to surface parking lots or, in some cases, structured parking, private garages, or carports.

Most zoning ordinances specify detailed design criteria and development standards for multifamily projects. Project density is usually set as a maximum number of dwelling units per acre or, in some instances, may be expressed as a maximum permitted square footage of building or floor area coverage per acre of land.

Minimum standards are adopted to guard against overcrowding, ensure access to light and air, protect privacy, and ensure compatibility between land uses. Most jurisdictions seek to locate multifamily residential development in areas where land costs are high. Typically, this type of development coincides with areas of considerable existing or planned investment in public infrastructure, or where proximate commercial retail and office activity would benefit from higher-density residential development. In this regard, multifamily housing often provides the buffer between nonresidential activity and single-family attached and detached developments.

Due to the more intense traffic generation resulting from the higher densities associated with multifamily housing,

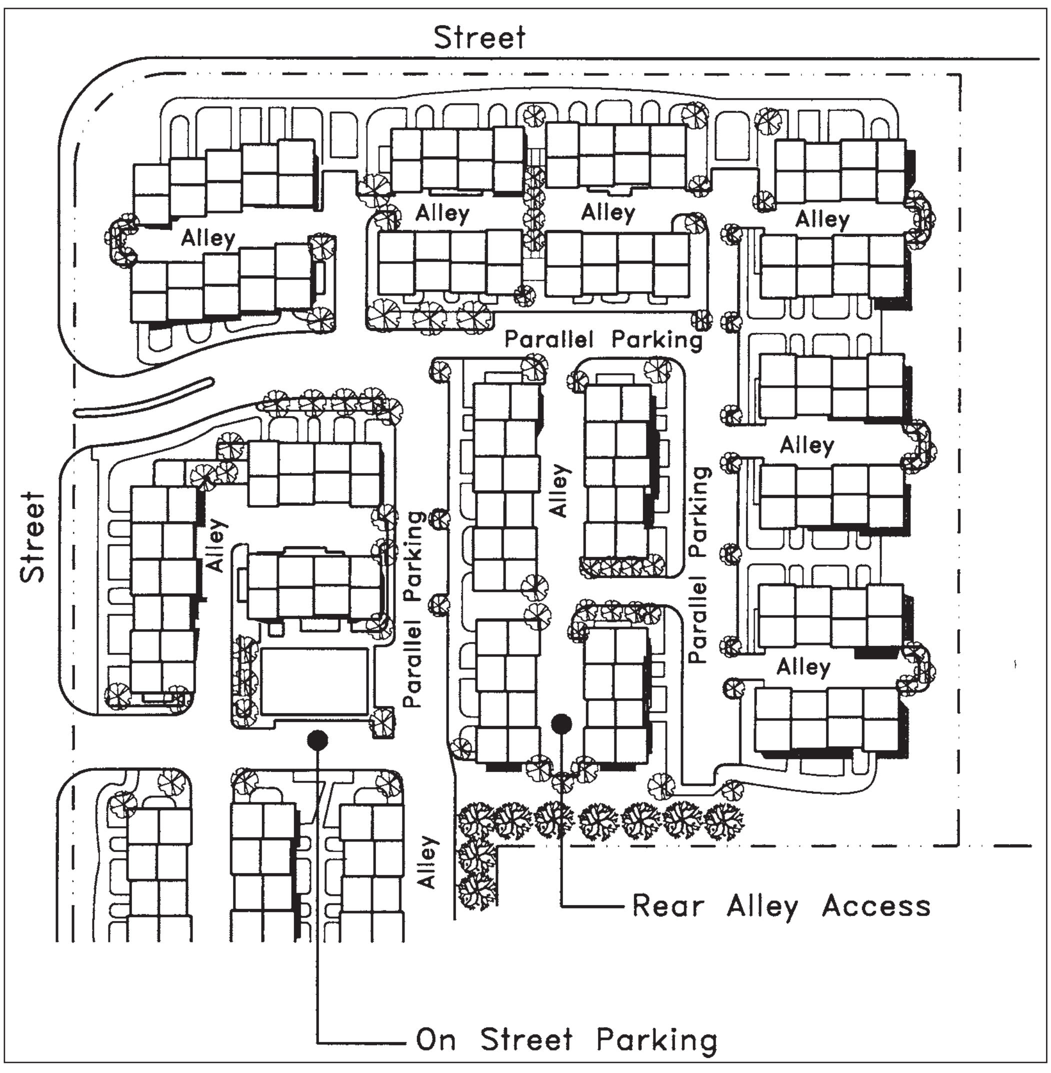

Figure 11.12 Traditional town house unit arrangement.

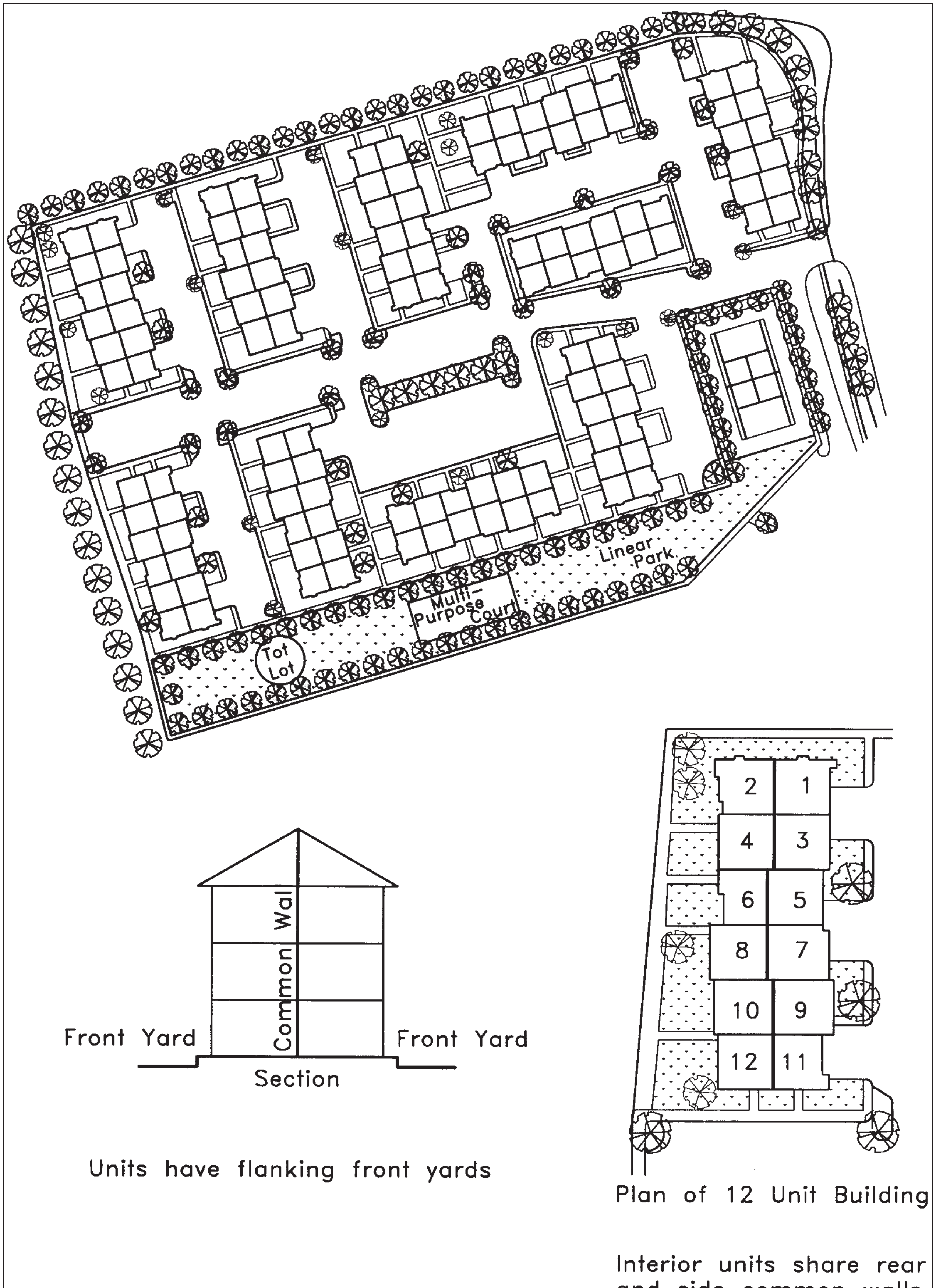

FIGURE 11.13 Back-to-back town house.

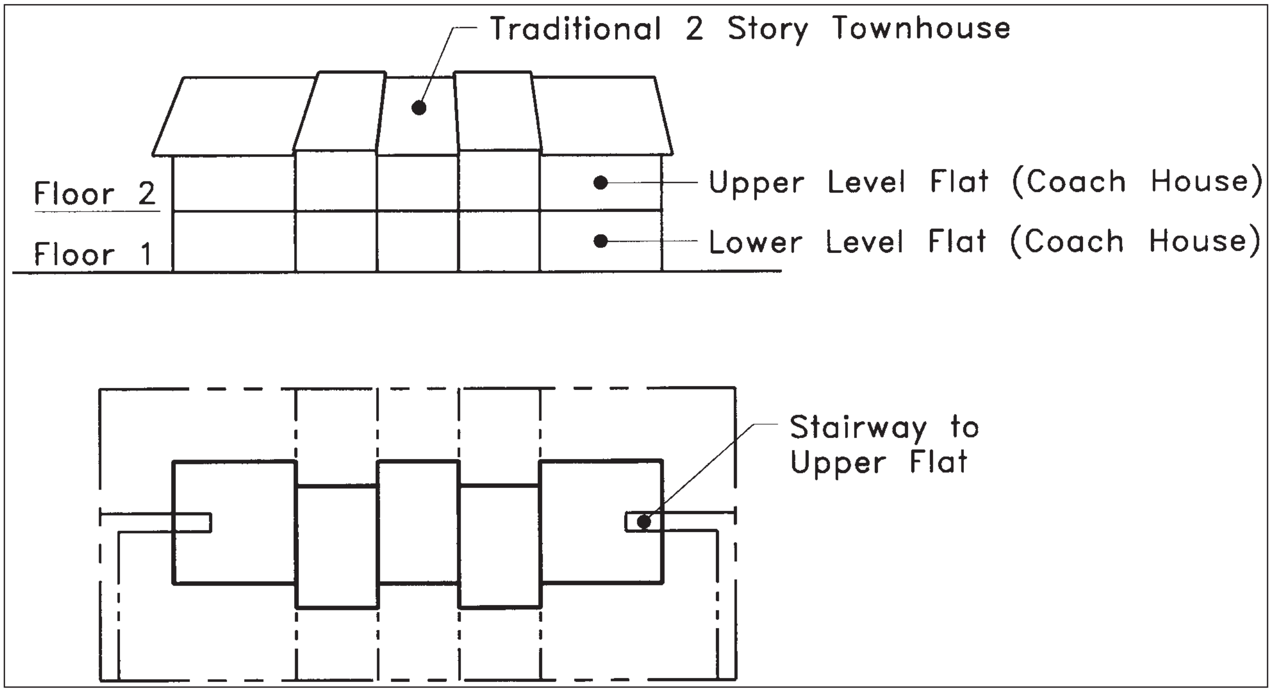

FIGURE 11.14 Combination town house and coach house arrangement.

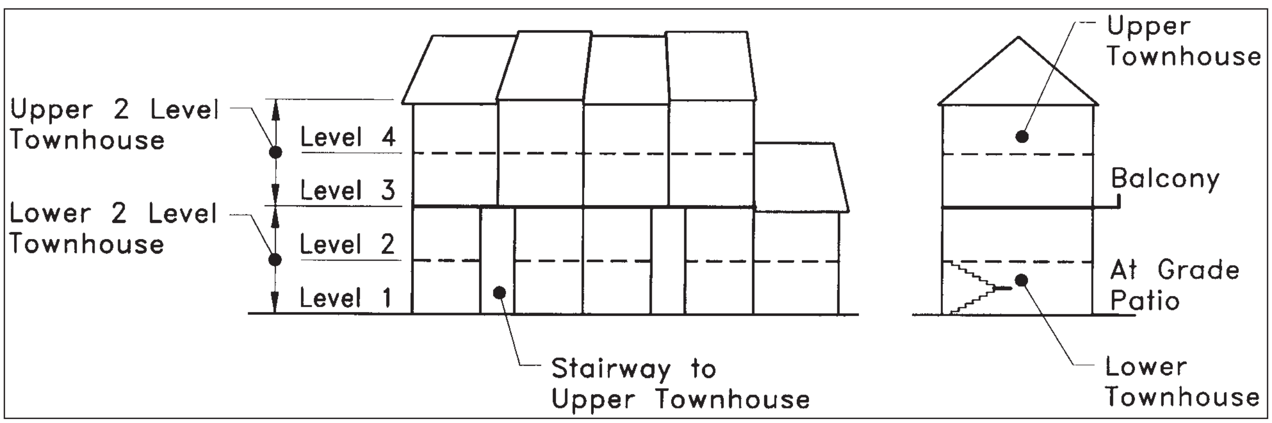

FIGURE 11.15 Piggyback or stacked town house.

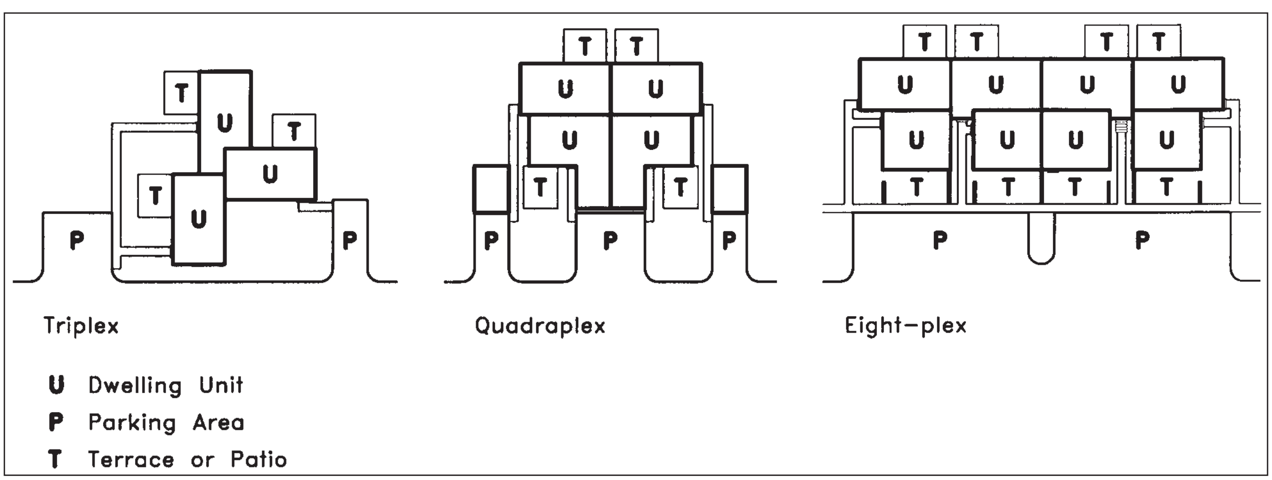

FIGURE 11.16 Typical multiplex combinations: triplex, quadraplex, eight-plex.

convenient access to major collector or arterial streets is desirable. Depending on the size of a development, local fire and public works officials may require at least two entrances or connections to a public street. This allows access to be maintained in the event that one entrance becomes obstructed.

Site planning for multifamily developments requires an appreciation and understanding of the proposed building design. The higher densities, size of structures, and relationship between structures and site elements leave less latitude than may be afforded in site design for less dense residential housing types. The placement of driveways, location and sizing of parking areas, and other infrastructure considerations require knowledge of building dimensions, elevations, and orientation.

Multifamily structures are generally categorized as either garden or low-rise, midrise, or high-rise structures. Distinctions and characteristics of each of these are described as follows.

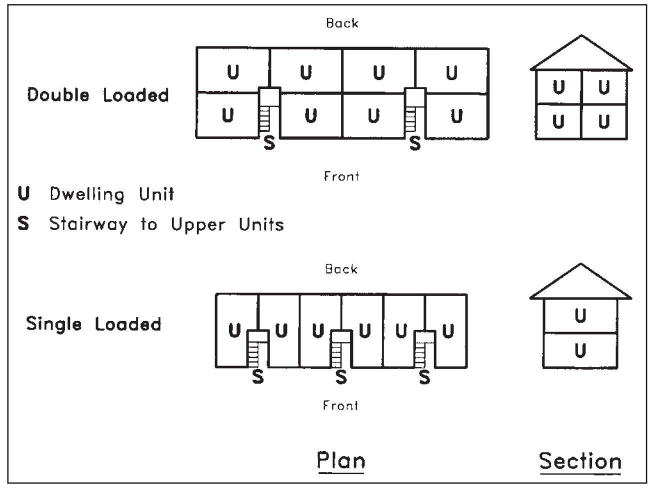

FIGURE 11.17 Example of double-loaded and single-loaded garden apartments.

Garden Apartments. Garden apartments, sometimes referred to as *walk-up* or *low rise,* consist of one- to four-story structures. The individual apartment units may be arranged along corridors or around common stairwells, which may be enclosed within the structure or unenclosed and integrated into the exterior architectural design. While some units may have direct private entrances at grade level, normally units share common entries. As the name implies, the garden apartment focuses on melding the dwelling unit to the building grounds. The building units are generally organized around landscaped open space and parking areas. Ground-floor units may have direct access to exterior patios or garden areas, and upper floors may have balconies or terraces, providing each individual unit with exterior living space.

Garden apartment building configurations vary depending on a myriad of marketing, program, and site considerations. They can be either single-loaded buildings, where the individual unit runs from the front to the rear of a building (through-units), or double-loaded arrangements, where each unit has a single (front or rear) exposure. In terms of site design, awareness of interior room organization and relationship to exterior space is important to promote desirable views and to enhance individual unit privacy. This is particularly important where parking is concentrated near the building. Provision of intermediate landscape between the unit and the parking area enhances the livability of the dwelling, particularly if it is the unit's sole exterior exposure. Figure 11.17 illustrates single- and double-loaded garden apartment layouts.

Garden apartments afford significant flexibility in site design due to the adaptability of various building forms to divergent site conditions. Unit densities can range from 10 to 20 or more units per acre, depending on the building configuration, unit sizes, number of stories, parking, open space, and amenity packages. In an effort to appeal to varying markets, garden apartment communities increasingly promote amenity packages that expand beyond the traditional swimming pool to include facilities complete with spas and exercise, game, meeting, and community rooms, as well as expanded site improvements including tot lots, court facilities, trails, and park courses. Multifamily residents increasingly desire amenities comparable to those provided in single-family residential communities. Even sheltered parking such as carports, or, more infrequently, individual garages, is an increasingly popular element in select garden apartment communities.

Midrise and High-Rise Multifamily Dwellings. Midrise multifamily residences are generally four- to eight-story structures. High-rise residences normally exceed eight stories. Both rely on elevators for vertical circulation. Individual dwelling units access common corridors. Units are generally arranged along opposite sides of the corridor, providing a single exterior exposure for the principal interior living spaces. While the economies of construction weigh heavily in favor of this arrangement, unique market considerations may prompt alternate design, such as single-loaded corridors, as in the case where a unique amenity mandates that all units have comparable exposure to the attraction.

Internally, buildings are organized around the elevator, utility, and a stairwell core, which may be central to the building floor plate. Entered at a common lobby, or multiple lobbies at differing levels if terrain permits, the corridors penetrate the building extremities, providing access to the individual residential units. Additional stairwells positioned at the farther reaches of the corridor provide an alternate means of access/egress. The concentrated need for service and delivery is generally satisfied by a central loading area, which is often located to the rear or side of the building, removed from main tenant access and view. Figure 11.18 illustrates a typical mid- and high-rise multiple family floor plate.

Four- to eight-story multifamily buildings can achieve densities of 30 to 40 or more units per acre. Provision for parking increasingly relies on subsurface or structured

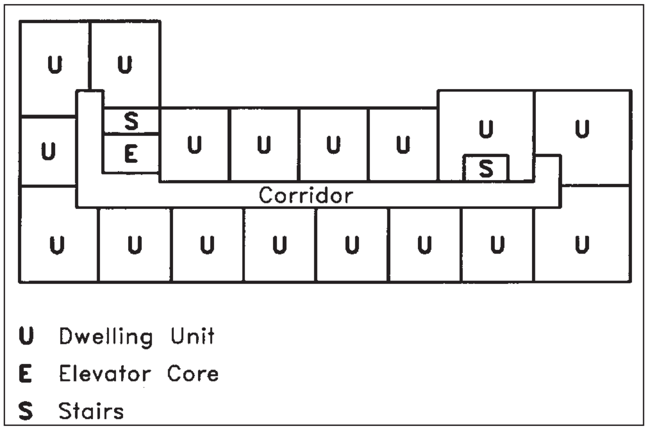

FIGURE 11.18 Typical midrise and high-rise multifamily housing floor plate.

arrangements to maximize land use efficiencies and promote tenant convenience and safety.

Many of the amenity provisions of mid- and high-rise residential buildings may be internal to the structure, but exterior elements may include a full range of recreational and leisure activity areas. In more urban settings, this may include indoor or rooftop swimming pools, landscaped arrival courts, and lush landscaped perimeters. On more expansive sites, the provisions may include tennis courts, elaborate pool facilities, and exterior exercise and recreation offerings in a parklike setting.

Site Design—Residential Development

Local zoning codes and planning documents generally provide the principal guidelines and criteria governing residential development patterns. These include stipulations as to means and methods for ensuring code compliance. Some of the more conventional considerations normally include the following:

- Maximum permitted density including means and method of calculation. Density calculations may require the omission of all or portions of a site area encumbered by environmental constraints such as steep slopes, floodplain, wetlands, major utility easements, and public rights-of-way.
- Minimum acreage assembly for select residential types. Often cluster or planned development districts require a minimum amount of acreage to be eligible for that zoning district.
- Minimum yard requirements, including front-, rear-, and side-yard requirements, may be expressed as a minimum dimension or relationship to the height of the building.
- Minimum open-space provisions, including potential distinction between usable open space, dedicated open space, and common green space. Ordinances may discount or cap the amount of public open space allowed as part of the project open-space calculation. Similarly, a percentage of the total open space may need to meet certain location, distribution, or performance criteria such as size, shape, and topographic considerations, or be exclusive of floodplains, utility easements, or wetlands.
- Screening and buffering standards given the specific use or use intensity proposed in relationship to the nature and density of adjoining uses.
- Maximum lot coverage.
- Minimum lot dimensions and frontage requirements including distinction between interior and corner units/lots, pipestem or flag lots, and cul-de-sac lots.
- Maximum number of pipestem lots permitted.
- Lot restrictions regarding inclusion of environmentally sensitive areas and utility easements.
- Parking and access criteria that may include the number of parking spaces required, limitations on public or private street length, and street loading capacities.
- Maximum building height and methods for calculating height.
- Minimal landscape or tree canopy requirements.

In attached and multifamily housing types, considerations may include the following:

- Minimum unit width or size.
- Limitations regarding maximum number of units that may be grouped together.
- Maximum distance between unit entry and parking.
- Variation in architectural facade and setbacks.
- Minimum setback from common property lines.
- Minimum distance between buildings.
- Standards and criteria for determining the number and placement of loading and service areas.
- Building and fire code requirements.

NONRESIDENTIAL LAND USE

Principal nonresidential development focuses on retail, office, and industrial land uses. The following discussion highlights the more prevalent building types and site considerations appropriate to each.

Market Considerations

Provision of retail, office, and industrial development programs can be prompted by a myriad of factors. They may include observation of a demonstrated need for local distribution of goods and services at a neighborhood or community level, recognition of an opportunity to fulfill a local jurisdiction's development goal in expanding either local or regional economic base, or recognizing local trends focusing on the growth, consolidation, or relocation of business ventures within an area. Regardless of the genesis or justification for such facilities, site design and site execution must be simultaneously sensitive to the requirements of the provider, prospective tenant and patron, site, and surrounding community.

Design Considerations

As with all land development activity, commercial site design criteria stem from two principal sources. The first consists of standards associated with the prospective use. This includes the spatial characteristics and site provisions requisite to housing and servicing the facility, its tenants, and customers. The second set of criteria concentrates on local land development plans and controls. While the zoning ordinance is the primary gauge for establishing site performance, other considerations such as environmental, fire, and safety compliance, factor heavily into facility and site design. This set of criteria may vary with the jurisdictions and the nature and intent of the specific land use under consideration.

Common Standards. Subsequent to determining that the proposed use is appropriate for a given property, setback, height, bulk, and other dimensional and performance standards constitute the principal site design criteria. These standards are normally contained in most jurisdictional subdivision and zoning regulations.

Floor Area Ratio. Nonresidential development is most frequently programmed and sized on the basis of the aggregate square feet of built structure relative to development site area. The common method of computation is the *floor area ratio* (FAR), a method of measurement expressed as the relationship of total building square feet to the total site area, as in Figure 7.4. As a reminder, the number of floors associated with the built product does not influence the floor area calculation. In the cited example, the 40,000-square-foot building might be constructed as a two-floor building of 20,000 square feet each, or a four-story building of 10,000 square feet each. The floor area ratio for a 40,000-square-foot parcel is 1.0 in each case. Most jurisdictions do not include parking structures in floor area computations. Similarly, exclusions may include portions of the building that are below grade or space programmed for select circulation, service, and support facilities. It is important to be aware of the method for calculating FAR in each jurisdiction.

Lot Size and Bulk Regulations. Minimum lot size, building height, bulk, setback, and yard requirements are normally stipulated in the individual zoning categories for nonresidential uses. The criteria generally vary in relation to the intensity of the desired development and the characteristics of the adjacent land use. Areas designated as more urban will normally require smaller setbacks from parcel boundaries. While a maximum building height may be stipulated, the permitted height of a structure may be governed by performance criteria. A common method of control focuses on maintaining a relationship of building height to peripheral yard setbacks. By designating an acceptable *angle of bulk plane* from the top of a building to a given property or parcel line, the setback can increase proportionately as the building height increases (see Figure 7.5). Other jurisdictions may express a minimum yard setback based on a given building height and simply stipulate that for every additional foot of building height the setback dimension will increase a set distance.

Parking, Loading, and Service. Criteria governing minimum parking, loading, and service are normally expressed in relationship to the floor area of the proposed building program. Typically, the zoning ordinance stipulates this standard as a minimum number of parking spaces to be provided on-site, although in some cases a portion of the parking may be provided off-site or in combination with adjacent uses. Jurisdictions vary in terms of how they express this relationship. It may be based on gross building square footage, or net building square footage, or net leasable or tenant area. The designer must understand the method of calculation, ascertain the minimum requirement based on public standards, and ensure that such a minimum provision has client and market acceptance. Unique program requirements or marketing considerations often prompt a need for parking and loading space provisions to be in excess of the minimum zoning criteria.

Landscape and Open Space. For nonresidential uses, this is typically expressed as a percentage of the total site area that is not encumbered with the building, vehicular circulation, and parking. While it is normally considered the residual portion of the site remaining for landscaping, in some localities it may be more conservatively delineated to exclude pedestrian walkways, patios, and similar site improvements, which are deemed impervious surface treatments. Landscape requirements are generally categorized as two main types.

Peripheral yard and buffer area requirements may be stipulated for nonresidential projects, which are deemed incompatible with surrounding land uses. These may be prescribed as a fixed dimensional width with certain pro forma landscape treatments or as a performance criterion requiring a combination of plant material and/or structural elements that provide an equal or improved buffering condition.

A second set of standards focuses on minimum landscape improvements required, given specific development program components. These may deal with shielding or screening of parking areas, service and loading zones, minimal streetscape standards, foundation planting, parking lot landscaping, or other specific concerns of the local jurisdiction.

RETAIL

Retail development may be loosely categorized according to the size and physical characteristics of the proposed facility. The principal types of retail locations include freestanding, strip, center, and mall arrangements of sales and accessory uses.

Freestanding Retail Development

The freestanding retail establishment has taken on reduced importance in the suburban market, given trends focusing on the aggregation of retail uses and the benefits of collective marketing, expanded visibility, and customer capture associated with more encompassing retail or mixed-use projects. Where a freestanding retail use does exist, it is generally positioned to respond to several sets of location criteria. It may be an establishment, sited on a separate recorded lot or parcel, which is part of a larger community of like uses, such as a town or village center or in a linear arrangement along a major road or highway. It may constitute a modest forerunner retail service in a geographic area of insufficient population concentration to warrant more expansive retail development. It may represent a national or local business with a sufficiently unique market to generate patronage at a location apart from other retail trade or whose functional requirements are best satisfied as a freestanding structure.

In today's retail market, freestanding retail establishments are commonly associated with locations within or proximate to larger retail spaces or shopping centers. Establishments such as restaurants, banks, movie theaters, bowling alleys, gasoline stations, office buildings, and similar singular operations may be located on separately recorded lots, sometimes referred to as *pad sites,* within the parking area or along the road frontage of larger retail centers.

The size and functional characteristics of such establishments vary considerably. However, building visibility, the number and convenience of customer parking, and the size and location of loading and service requirements generally represent the primary site design criteria that establish the pattern for such uses. Where such a facility is contemplated at isolated locations, one can anticipate a greater need to ensure measures of compatibility with surrounding development. Integration of freestanding retail uses as an adjunct to neighboring strip, center, or mall retail development patterns generally present less difficulty in ensuring community fit and may afford advantages to the extent that parking, street improvements, and other infrastructure considerations may serve multiple users.

Strip Centers

Strip centers literally represent the aggregation of retail uses in a linear arrangement, most notably with their front facades paralleling roadways or positioned in an "L" configuration at the intersection of major transportation routes. Generally, the establishments are one store deep, share common interior walls, and are linked by a common pedestrian walkway across the storefronts. The bulk of parking is aggregated into one or more principal parking areas normally located between the store facade and the street. Strip centers rely on a strong visual relationship to the adjacent street frontage for identity and marketing. Strip retail arrangements can vary in size; however, once the linear distance across the collective storefronts exceeds ±400 feet, pedestrian circulation between stores begins to subside. Once a larger retail establishment, such as a major grocery store or drugstore, is introduced into a linear arrangement, the distinction between strip and retail center becomes less noticeable. Figure 11.19 illustrates the typical strip center configurations.

Retail Center

Ascertaining definitive criteria that distinguish a strip center from a retail center is subtle and often obscured in popular reliance on the latter term, given the negative connotation that has come to overshadow the former. Retail centers share in their reliance on common parking areas, major pedestrian circulation across storefronts, and maintenance of a reasonable relationship and visibility to adjacent roadways. A distinction can best be found in the number of potential anchor or larger retail establishments that are located in a retail center, an abandonment of sole reliance on a linear arrangement for all of the retail establishments, and the introduction of smaller "pad" sites within the retail center site. Centers often are arranged in an "L" or "U" shape, with anchor stores occurring at the building extremities and/or central to the parking lot. These arrangements take advantage of parcel depth, and lining multiple sides of the parking area with stores reduces the distance between the parking stalls and a variety of retail establishments. The introduction of freestanding retail establishments, such as banks, gas stations, and restaurants, at the center or along the roadway frontage prompts a functional complexity to a retail center and requires careful attention to site details to ensure sufficient visibility, access, and convenience of parking, service, and loading. Figure 11.20 represents a typical retail center design.

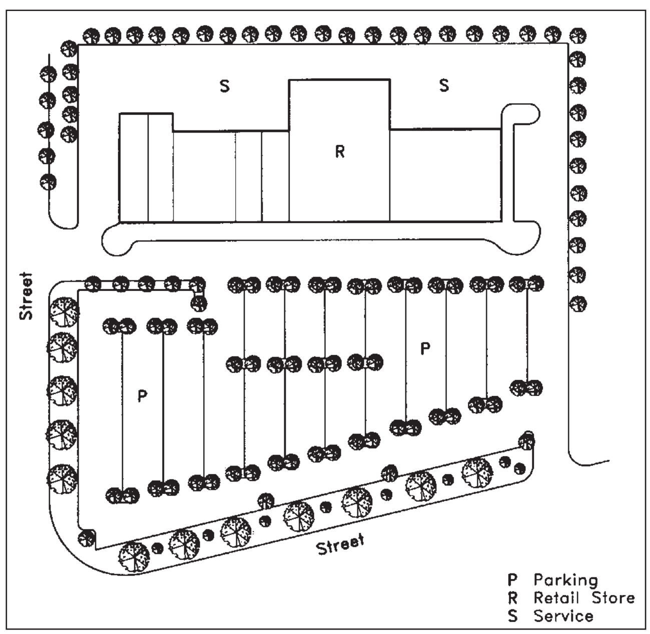

FIGURE 11.19 Typical strip center arrangement.

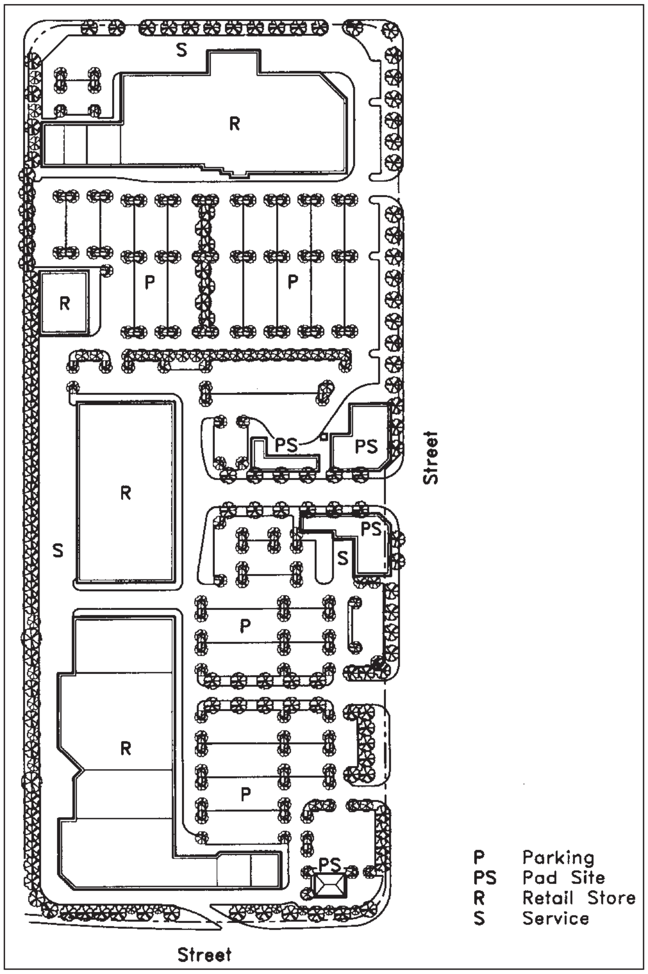

FIGURE 11.20 Typical retail center arrangements.

Retail Mall

The distinguishing characteristics of the retail mall include the separation of major pedestrian movements from peripheral vehicular parking and circulation. Generally located between opposing store facades, an internal pedestrian walkway or mall may be either open or under a roof. Both arrangements provide an opportunity to direct customers along expanses of intervening retail establishments.

A typical mall is presented in Figure 11.21. A normal convention in organizing on-site vehicular circulation is to position a service drive at the building perimeter and a perimeter road near the outer edge of the major field of parking. Major approaches to the mall tend to be aligned with main store anchors. In many instances, freestanding uses (pad sites) may occupy acreage between the outer mall loop drive and the perimeter street network.

Figure 11.22 illustrates the front-sided multilevel parking arrangement employed at the Tysons II retail mall in Fairfax, Virginia. In the background (right rear), parking decks have been constructed over former surface parking lots to accommodate the expansion of neighboring Tysons I.

There is a considerable range in the size of retail malls, with major regional serving facilities often exceeding 1 million square feet of leasable area. Increased reliance on structured parking can assist in reducing distances between parking areas and retail stores. The resulting site solution often entails the bridging of peripheral service drives around the center perimeter and, in the case of multilevel malls, may result in pedestrian walkways that connect to various levels of the center.

Main-Street Retail Development

Main-street retail developments are increasingly encouraged by local ordinances and provide an alternative to the indoor mall or the modern-day strip center, both traditionally organized around a large area of parking. Unlike a strip center, or mall, the idea behind the main-street retail concept is window-shopping, or appealing to the pedestrian, and is modeled after the historic setting of a small-town main street, or downtown, with boutique stores, family-owned shops, and live/work units. Main-street retail developments create a destination or node in the community and provide its users with a sense of place, encouraging the users to interact with the development. The shops and other commercial components front directly on the sidewalk, with either rear parking or angled, parallel, or head-in street parking separated from the sidewalk by a landscape strip or planters. Most main-street retail areas are flanked by additional shops, offices, restaurants, or additional commercial uses. Often anchored by a large retail center, a hotel, or other type of main attraction, this type of retail development often fits seamlessly into the surrounding community and can serve as a transitional element between mixed-use areas and strictly (less dense) residential areas. Main-street retail is similar in architectural style to town houses. It may be single-story, two, three, or more stories and may, in mixed-use scenarios, have residential or office space on upper levels.

Please refer to the color insert for a representative example of a main-street retail plan.

Retail Center Design Considerations

Site design for retail centers should be predicated on overall customer ease in identifying and locating the individual tenants within the center. Convenience of vehicular access, adequacy and placement of customer parking, and safety of pedestrian movements between parking areas and retail establishments are all fundamental site-planning considerations. A secondary set of criteria focuses on the internal servicing and operation of the center, particularly in regard to separation of service, delivery, and loading facilities. Typically, reasonable convenience of parking areas (to the retail establishment) imposes a limit on the maximum acceptable distance between the most peripheral parking space and the center itself. This distance generally approximates 400 feet, which is the equivalent of a two-minute walk.

Beginning at the site perimeter, design considerations for retail activities should include the following.

Figure 11.21 Retail mall arrangement. (Photo by Larry Olsen)

Center Orientation to Surrounding Road Network. Retail establishments should be positioned to take advantage of visibility to abutting public rights-of-way. Leasing agents maintain that the greatest market asset of a retail center is unobstructed visibility from adjacent roadways. In expansive centers, the major anchors are usually singled out for this elevated position, with smaller flanking or interior store locations dependent on foot traffic generated by the anchor. There are ample examples of successful retail centers that do not rely on excessive road exposure. It should be cautioned, however, that many of these more introspective centers are located in planned communities, governed by site and architectural guidelines and operate within an environment where the location of competing establishments is stringently controlled.

Sizing. The distinctions between freestanding, strip, center, and mall arrangements are related to the architectural massing and organization of retail space. With the exception of freestanding retail establishments, whose size and location may be a function of numerous unique circumstances, the size of a retail project and the profile of its resident tenants relate to their intended service population. Normal conventions include a distinction between neighborhood centers, community centers, and regional centers. Although jurisdictions may actually provide precise definitions for each in

FIGURE 11.22 Retail mall arrangement with structured parking. (Photo by Larry Olsen)

their respective zoning documents, general definitions of each are as follows:

- *Neighborhood centers* generally service a population of 2500 to 40,000 or a 1.5-mile radius. They may range from 3 to 10 acres in size, approximate 40,000 to 100,000 square feet of gross leasable space and may include a supermarket or drugstore as the lead tenant. Other establishments focus on convenient consumer access to frequently purchased goods and services.
- *Community centers,* located on 10 to 40 acres, range from 100,000 to 400,000 gross leasable square feet and service an area of 3- to 5-mile radius, a population of 20,000 to 50,000, or the equivalent of several neighborhoods. The range in uses may include a supermarket, drugstore, general merchandise, or similar offering, as well as attendant smaller retail establishments.
- *Regional centers* generally comprise retail assemblies sufficient to provide a full range of retail goods and services. They may range in size from 400,000 to over 1,000,000 square feet, service areas approximating an 8- to 10-mile radius or a 20-minute drive, and populations of 100,000 or more. They generally contain spe-

cialty offerings and full-scale department stores, as well as supporting establishments. Sites may range from 40 to over 100 acres.

Vehicular Circulation. Transportation circulation is extremely important to retail site design. Access and egress points should be well articulated and smoothly transition to the adjacent public road system. Ideally, multiple access points, sufficiently distanced to promote safe alternate approach routes, should be secured. Traffic routes should attempt to separate service vehicles from customer traffic. A separate site entry/egress point for service traffic is ideal but may be impractical in many instances. Customer vehicle routing should provide as near a continuous drop-off zone along the facade of retail establishments as possible. A perimeter circulation route, ring road, or street network to access and exit the parking area can assist in reducing reliance on travelways nearer the building and minimize the potential conflict between through traffic and the discharging of passengers and/or loading of merchandise. In more conventional retail arrangements, depending on the depth of the parking bays and the size of the retail center, intermediate travelways midway between store facade and perimeter boundaries can assist high traffic volumes in navigating parking areas and overall traffic flow.

Service traffic should be directed to separate loading areas and service docks. Normally this occurs to the rear of the retail stores, where it can be appropriately screened and refuse containers can be shielded from public view. Loading bay approaches and service drive design should conform to appropriate geometrics for the size and number of vehicles necessary to adequately serve the development program. Entry drives should be of sufficient length for vehicles to adequately enter the site prior to contemplating major turn movements. Exits should provide sufficient stacking space to accommodate safe transitions into adjacent roadways.

Parking. The minimum number of parking spaces required to support retail activity is normally specified in the zoning ordinance, as is the required number of loading spaces. Criteria are usually expressed as a ratio of parking spaces to the square footage of the development program. The standards may vary depending on the service characteristics of the retail establishment. More spaces may be required for enterprises with higher customer occupancy, such as restaurants, than for stores with more extensive display and stock storage space, such as a furniture store. The required number of parking spaces is normally between four and six spaces per 1000 square feet of gross leasable area. The local zoning ordinance should be consulted for specific standards. Requirements for certain retail uses may require provision of additional spaces based on the number of employees or, in the case of restaurants and theaters, on seating capacity.

Although freestanding and smaller centers may accommodate parking stalls parallel to the pedestrian walkway immediately in front of the retail store, larger retail centers generally preclude parking from the vehicular drop-off and pedestrian approach zone. In these larger retail centers, the parking area normally begins beyond the frontage service drive and drop-off aisle. While the configuration of the parcel may warrant a different arrangement, parking aisles are generally positioned to run perpendicular to the store facade. This arrangement promotes ease and safety in pedestrian movements from their parked vehicles to the store entries.

Retail parking normally locates the major parking area between the retail establishment and the major frontage road. In larger multisided centers, such as shopping malls, parking generally encircles the center. In planned communities, where stringent design standards are in place, it may be necessary to buffer parking areas from public view or locate them to the rear of the retail area. Such an arrangement minimizes the visible expanse of parking as well as promotes the retail building form in a forward position on the site to assist in defining the street edge. This latter approach is key to traditional design principles that give heightened importance to pedestrian circulation, the use of building architecture, and massing to enhance street definition.

Other Considerations

The sizing of retail use for a particular site and the establishment of the building floor plate should be done in consultation with both client and retail marketing professionals. While there are general rules of thumb associated with the provision of retail space, rapid changes in marketing practices and the unique circumstances associated with many individual retail establishments often prompt a tailored response, which may vary from the norm. As a foundation, however, several general planning guidelines are appropriate for conceptual retail site planning.

- Single-story retail programs generally result in an effective floor area ratio of 0.18 to 0.25 depending on the configuration of the parcel and unique site conditions. Multilevel malls with structured parking can result in a floor area ratio exceeding 0.5.
- Conventional retail parking requirements of ±5 per 1000 square feet of building area generally requires a parking area approximately 2 to 2.5 times the gross area of the building floor plate.
- Individual store depths generally range from 40 to 150 feet, while widths may be approximately 20 to 150 feet. Often, the ability to partition individual tenant space is dependent on the method of construction and dimensions imposed by modular structural components. The clear span between such modular supports is often referred to as a *building bay*.
- Mall widths generally approximate 30 to 40 feet along pedestrian corridors. The distance may increase to 60 or more feet at intersecting corridors, or where feature courts or common areas are introduced along the pedestrian spines.

- In enclosed malls, 15 to 20 percent of the total gross floor area may be included in common areas such as corridors, courts, and common mall area.

- A reasonable walking distance between major retail anchors in an indoor mall is 700 feet. is A maximum desirable distance from parking areas to retail entries is 400 feet.

- Large center retail layout is dependent on the number and positioning of anchor stores. Anchors are normally located at the building end or building intersections to provide each establishment with multiple facades and entrances for maximum building exposure and accessibility. In smaller single-anchor centers, the anchor should command a fairly central and visible location, with smaller stores flanking each side. This arrangement assists in promoting market identity, places the larger user central to the field of parking, and positions the smaller establishments to benefit from the pedestrian circulation generated by the larger store. In multiple-anchor malls or centers, the expanse between the major stores is most valued.

- Large retail centers may reasonably support a multilevel building program. In large retail centers, the internal vertical circulation within multilevel anchor stores augments core mall escalators and elevators in directing pedestrian movements to smaller stores on upper levels. Smaller neighborhood and community centers, dependent on ease of access and short duration of visit, seldom include second-story retail space. If land costs or unique market circumstances warrant a second level, it is often occupied by office- or service-related uses.

- In a large mall, a major anchor generally exceeds 100,000 square feet of gross leasable area. In neighborhood or community centers, the principal food market or drugstore anchor tenant may range from 25,000 to 50,000 square feet.

- Design principles for power centers or big-box users generally conform to those for comparably organized retail centers, be they stand-alone, strip, center, or mall arrangement. The size of the individual establishments, ranging from 40,000 to 100,000 square feet and up, however, requires additional attention to potential vehicular and pedestrian circulation conflicts and the enormity of desired parking field.

OFFICE USES: OVERVIEW

Suburban jurisdictions have experienced a tremendous amount of office development over the last several decades. The scale of this activity has evolved from tacit provision of small-scale office and administrative space serving locally based municipal, medical, and professional services to increasing accommodation of a major share of the employment base of metropolitan areas. The type, scale, location, and arrangement of these facilities vary considerably. They may house single or multiple tenants and may be occupant owned or leased. Construction may be prompted by the specific program requirements of the occupant or be initiated on a speculative basis in response to existing or anticipated market demand.

In office development, zoning regulations most frequently focus on building "bulk" and site characteristics. Specific controls generally include criteria detailing acceptable limits for building site coverage, floor area ratios, building height, and impervious cover allocations. Typically, minimum standards include provisions for parking and loading, building setbacks and yard requirements, lot size, and open space provisions. Additional criteria may refine the quality of the open space in specifying the extent to which it must be landscaped to qualify as landscaped open space or "green space." These controls vary according to the intensity and character of existing development within the community. Controls may be less stringent in more densely developed areas surrounded by compatible land uses.

Four office types or configurations are commonly found in suburban locations. These include the freestanding office building, the office park, the garden office complex, and the town house office.

Freestanding Office Buildings

Freestanding office buildings generally consist of a self-contained building on an individually recorded lot or parcel. The building may accommodate single or multiple users or tenants. Space may be rented or owned by the tenant or tenants. Its occupancy of a separate recorded parcel or lot and need to singularly satisfy appropriate zoning criteria are perhaps the only generalizations that may be made about the freestanding office structures. They can range from multifloor, multitenant structures with relatively high floor area ratios and heavy reliance on structured parking to small, single-tenant buildings serviced entirely by surface parking.

The location and context of the surrounding land use factors heavily into the nature and execution of site design for office buildings. A more urban siting, with higher land costs, may confine the size of the building footprint and prompt a taller structure to secure the desired square footage. Such buildings may demand stronger street presence to satisfy pedestrian access, increased reliance on structured or below-grade parking, more intensive landscape development associated with modest residual open space, and greater restrictions on the number and location of access points.

Buildings in less urban locations benefit from lower land costs and may result in larger building floor plates, lower building height, and more expansive site improvements, including reliance on surface parking. Building siting may or may not demand a strong street presence. Institutional and corporate clients may prefer a more secluded setting in which the building is buffered from surrounding uses for purposes of privacy or security.

Office Park

The office park requires coordination and control of a property assembly suitable for multiple office buildings and support services. Not unlike its residential counterpart, the planned community, the office park seeks to locate individual freestanding office structures in a setting enhanced by open space and landscape amenities. In addition to in-place jurisdictional controls, supplemental guidelines and covenants generally ensure that all development within the park meets certain predetermined standards. The internal street system and infrastructure are normally planned and developed by a single entity. This results in the availability of sites suitable for sale for individual building construction. The availability of appropriately zoned office acreage with in-place infrastructure is attractive to prospective owners or tenants who may have neither the time, the resources, nor the inclination to subject themselves to time-consuming front-end requirements necessary to transform raw land for office development. The proximity of similar and related uses coupled with the shared infrastructure and amenity packages, which may not be economical to any single user, are inducements for location within a well-planned and executed office park. Shared infrastructure elements may include both on- and off-site utility and roadway improvements as well as on-site amenities. Amenity provisions can range from extensive woodland preservation areas and water features to common recreation, athletic, and social facilities. Depending on the location and scale of the park, hotel, select retail, and day care facilities may also be included. Figure 11.23 presents an office park parcel plan.

Site development considerations in office park design, as with any complex multiuse building program, requires careful consideration of existing site features, with criteria imposed by local jurisdictional controls, prospective tenant requirements, and sound engineering and design practices.

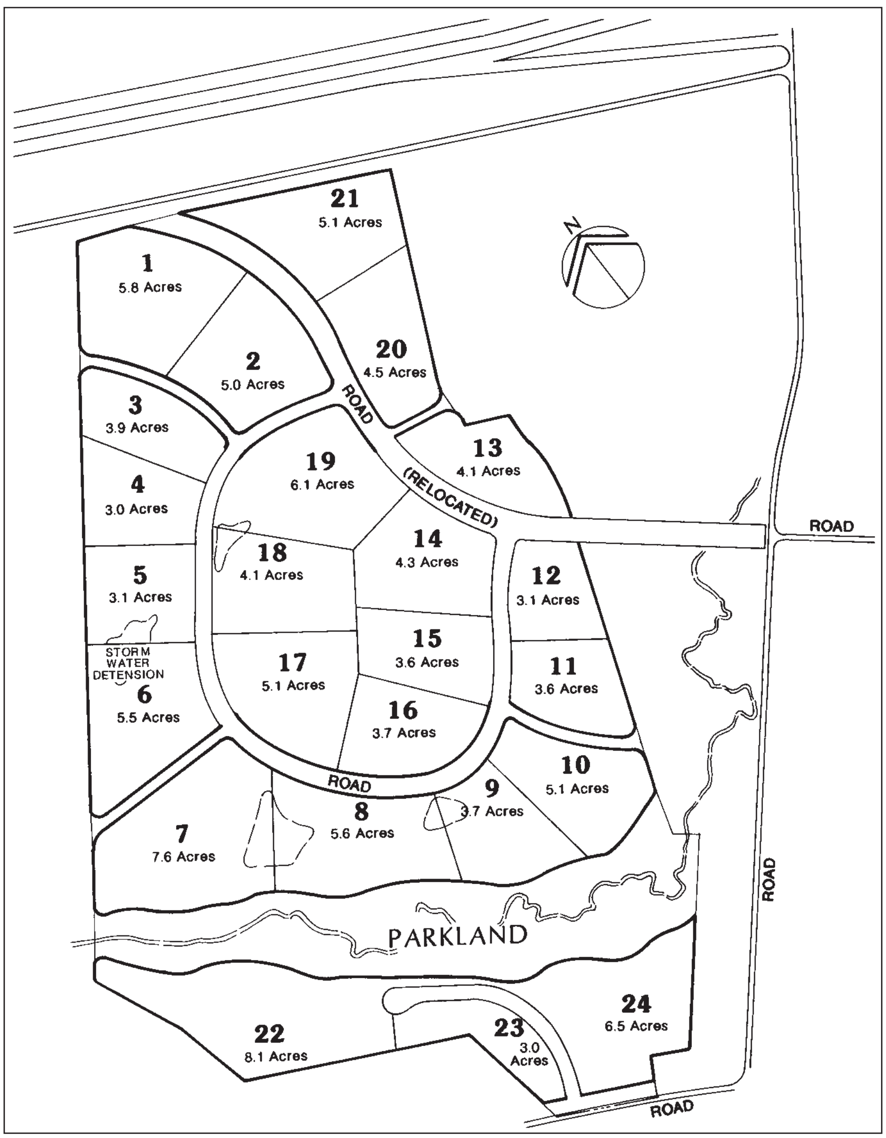

FIGURE 11.23 Example: office park parcel plan.

Site systems, including vehicular and pedestrian circulation, must be developed to balance the overall needs of the park with those of individual building sites. Parcelization plans require dimensional accuracy and flexibility in ensuring sales and marketing. The likelihood of surface, structured, or below-grade parking has bearing on the relative development intensity that may be anticipated on any single site within the park, as well as the aggregate development potential for the overall facility.

Garden Office

The garden office generally provides for multiple tenancies in a low-rise assembly of buildings. It is particularly attractive to professionals and service-oriented businesses that benefit from proximity to surrounding residential areas. Its scale is generally conducive to locations near residential development, and the architectural style and scale may closely resemble garden-style multifamily residential construction. Ranging from one to three stories, the tenant space is normally divided horizontally, by floor, with individual entry often open to common stairwells. Multilevel structures may be equipped with elevators. Buildings may be arranged linearly, with common parking areas to the front, or clustered around parking areas or pedestrian courts. Where the terrain permits, entry may be gained at different levels of the building, providing the additional benefit and convenience of having associated parking at the same level as tenant space.

Town House Office

Low-rise office space compartmentalized vertically may be classified as town house office. Similar to its residential counterpart, each unit is organized to access directly to the exterior at grade level. The individual units may be single story or multiple levels. While normally a single tenant occupies each unit, smaller businesses may occupy separate floors of the same unit.

Town house office, like garden office, benefits from a scale that is conducive to a location near residential areas. Its tenant profile focuses heavily on occupations and professional services that seek that proximity. Typical layouts vary from linear to cluster patterns, and topography may facilitate use of the underside of the unit to accommodate a separate tenancy.

Office Design Principles

As with retail design, there are a few governing principles that are appropriate for office parcel layout and design. Foremost in this checklist are the specific requirements of the local jurisdiction. Zoning conditions may encompass building setbacks, buffering and screening requirements, and minimum parking counts, as well as governing the height, bulk, and size of the building program. Municipal controls may reflect pro forma criteria attributable to the parcel zoning or tailored to the unique circumstances of a site relative to surrounding land uses and/or on-site characteristics.

Design of these elements requires attention to the details of site organization and function. Considerations generally include the following:

- Sensitivity in orchestrating an appropriate external image, given potential roadway and land use adjacencies
- Site and building access that is legible and avoids congestion
- Efficient floor configurations that are conducive to leasing and occupancy requirements
- Sufficient parking, given tenant requirements
- Parking that is convenient to both occupant and visitors
- Site development and amenity provisions that are tailored to meet the requirements of developer and tenant
- Service and loading design that avoids conflict with normal building operations and is adequately screened from occupant and community view

The range of land use intensity attributable to conventional office use can vary considerably. Floor area ratios in excess of 1.0 are not uncommon in proximity to suburban mixed-use centers. However, suburban office intensities for conventional freestanding buildings more commonly range from a 0.25 to a 0.4 FAR, which result in building heights of one to four stories. The 0.4 FAR is normally considered the threshold at which an office building may be surface-parked while maintaining reasonable distances between the building and outer perimeter parking areas. An FAR greater than 0.4 normally requires significant reliance on subsurface or parking structures.

Although the traditional parking ratio for office use averages four spaces per 1000 square feet of net leasable space, the requirement may be loosened at locations close to public transportation or mass transit. In some circumstances, parking demands may be lessened if a disproportionate amount of building space is to be utilized for operations that are not employee dependent. On the other extreme, tenancy that requires high visitor turnover, such as medical office uses, may necessitate higher parking ratios. Similarly anticipated building occupancy by tenants employing smaller per-employee work areas, such as telecommunication call centers or 24-hour operations with overlapping work shifts may require parking that exceeds conventional office criteria.

INDUSTRIAL

Local development standards governing industrial activity have often augmented traditional zoning criteria that establish controls on maximum land use intensity, minimum lot size, setbacks, and building bulk and height, with specific performance standards that serve to categorize not only permitted types of industrial activities but minimum standards associated with their operation. Performance criteria may be tied to standards governing air pollution control, fire and explosion, radiation hazard, electromagnetic radiation and interference, liquid and solid waste discharge, and noise, vibrations, and light source considerations, among others.

The nature, extent, and complexion of industrial land use have changed dramatically in the last several decades. The expansive single-purpose facilities focusing on raw mineral extraction, product manufacturing, and assembly have been overshadowed by the provision of more flexible space that focuses on product distribution, research, and service industries. This transition has had a profound impact on the location requirements of industrial uses and the physical characteristics of industrial facilities. It has also lessened community resistance to a genre of uses that do not pose the level of incompatibility historically associated with industrial activity, including potential air pollutants, hazardous waste by-products, acoustical and vibration impacts, and heightened fire and safety considerations.

While heavy industrial, extractive mineral, and expansive processing facilities can be found in suburban locations, escalating land values combined with new technologies have often prompted many of these types of industries to relocate to areas where land cost, labor supply, and use controls are more conducive to their operations. In their stead, activities focusing on research and development, smaller-scale electronic assembly, data processing, telecommunications, product distribution, and warehousing have become more significant industrial components of many metropolitan areas. The noxious characteristics of traditional industrial activity located proximate to railroad lines has given way to expansive industrial and technology parks whose locations are governed more by convenient access to interstate highways, airports, and population centers.

Building programs associated with industrial activity generally rely on a strong building-to-ground relationship. This is in keeping with their dependence on truck transport as a principal means of product delivery and assembly operations, which rely on horizontal line arrangements and on-grade structural conditions to support machinery and expansive storage and warehousing requirements.

Sensitivity to the diversity in industrial uses of both historic and contemporary facility types has prompted most jurisdictions to adapt their zoning ordinance to provide varying standards for select classes of industrial activity. Classifications normally are differentiated between light, medium, and heavy industrial uses. The gradation was strongly related to the potential level of land use incompatibility anticipated between the subject industrial operations and adjacent land uses. In recent years, more fine-tuned distinctions have been made to accommodate the less onerous industrial characteristics associated with research and development (R&D) activities. In R&D parks and similar institutional environments promoting scientific research and product development, training and offices manufacturing or product assembly may be either nonexistent or only a diminutive part of the overall facility operation. The potential land use conflicts and levels of incompatibility characteristic of traditional industrial activity may be negligible. Building programs that reflect some of the more typical industrial arrangements found in the suburban market are discussed in the following subsections.

Heavy Industry

Precedent activity, proximity to raw materials, natural resources, power sources, and location at major transportation hubs and population centers are several factors that prompt the need for heavy industrial activity in otherwise urban and suburban markets. Generally, these activities trigger a litany of potential use conflicts. Zoning criteria normally focus on minimum dimensional standards and performance criteria to reduce or contain the impacts of such uses. Facilities may include intense manufacturing operations; heavy equipment, construction, and fuel yards; mining and quarrying; major transportation terminals; and other equivalent concentrations of potential noxious uses. Heavy reliance on truck transport favors industrial locations with reasonably convenient access to major arterial or collector roads or, in the case of interstate trade, major freeways and highways. Reliance on rail and water access continues to be important to certain types of industrial activity.

Heavy industrial uses tend to be land consumptive in terms of building program or exterior space requirements for vehicular movement and storage. Floor area ratios of 0.5 to 1.0 with surface improvements as high as 80 percent to 90 percent of the usable site area are common. Site design issues focus on adequacy of site entry and egress; internal site circulation with regard to potential separation of visitor, employee, service and facility operating needs; and screening of exterior storage and loading areas from external site views.

Medium-Intensity and General Industrial Use

Product fabrication and assembly operations, storage, and similar industrial operations in suburban locations tend to be categorized as light manufacturing. They offer reduced levels of noise, smoke, glare, and other environmental pollutants normally associated with the more intense or heavy industrial activity. Development considerations and site design issues do not differ substantially from those previously cited. Characteristics associated with a smaller scale of operation or activity that has a relatively less invasive impact on surrounding land uses often accommodate mitigation of concerns within the confines of the site.

Light Industrial Use

The light industrial classification affords more lenient standards, given the more compatible nature of permitted uses. Uses include activities considered least obtrusive and operating under high performance standards relative to off-site impacts. Floor area ratios may be less expansive and range from 0.4 to 0.5 FAR, and operations including storage may be required to be entirely under roof.

Special Industrial Use Patterns

Contemporary development patterns, evolution in building technology, and opportunities or requirements for the containment of noxious impacts has fostered a radical alteration in industrial prototypes over the last several decades. This has resulted in refinements in standard land use controls, which are sensitive to trends focusing on the aggregation of compatible industrial activities in planned industrial parks. The emergence of zoned industrial districts qualified as institutional, research, technology, warehouse, and distribution centers reflects unique sets of operating requirements, an affinity for like-kind uses to collocate, and market-driven pressure for elevating the site aesthetics of select industrial land use activities.

Local public controls may afford opportunities for the creation of an industrial district that caters to uses that can demonstrate compatibility with surrounding land activities. Minimum land assembly, larger minimum lot requirements, increased setback, screening and buffer requirements, increased landscape and open-space standards, reduction in allowable building profiles, more restrictive building bulk criteria, and allowable land use intensities as low as 0.25 FAR, assist in ensuring reduced visual impact on surrounding areas for uses that can demonstrate no adverse off-site impacts. Positioning more compatible activities at perimeter locations often assists in creating an overall planned industrial development that affords considerable variety in tenancy and use opportunities. A typical industrial park is presented in Figure 11.24.

Industrial/Office/Retail Hybrid Building Forms

One of the more notable and popular building forms that has emerged in suburban development markets is the flex-tech or office showroom prototype. The overall building shell is designed to allow the compartmentalization of separate units depending on the spatial needs of individual ten-

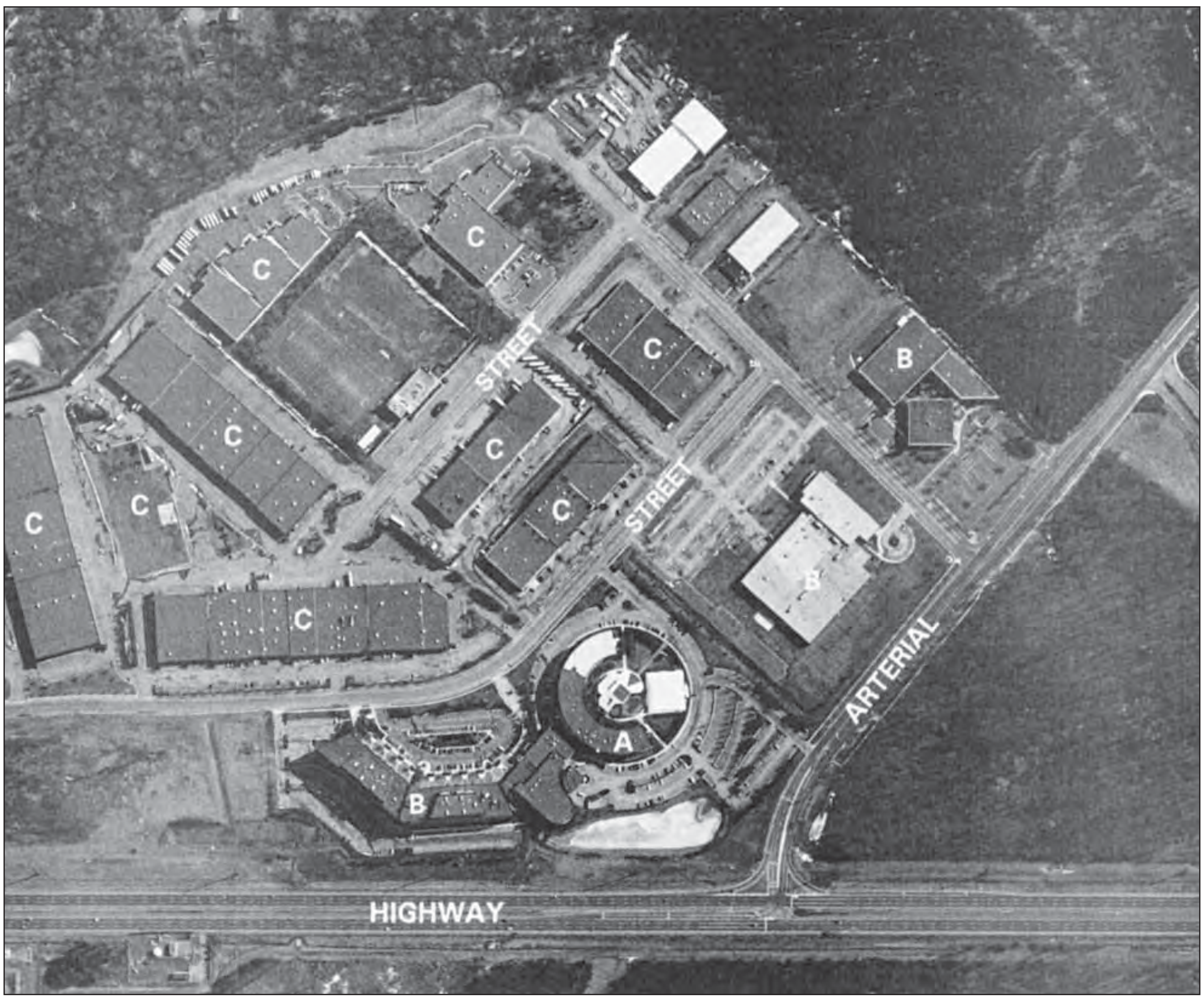

FIGURE 11.24 Example industrial park, Renaissance Park, Fairfax, VA, is an example of a hybrid industrial park with (*a*) hotel located on a major highway frontage, (*b*) traditional office/research and development building types with separate parking areas and limited loading facilities at more visible locations, and (*c*) flex industrial building types with visitor/employee parking along the building frontage and a continuous service/loading area running the rear building length. (Courtesy of Air Survey Corp.)

ants. Generally unit, or bay, sizes are tied to the modular dimensions of the building structure (the roof span between vertical support elements). Common modules range from 20 feet to 45 feet. Similar to construction techniques employed in conventional retail centers, the overall length of the building may be divided by interior walls providing each occupant an exterior exposure on both the front and service sides of the building. The front exposure is generally devoted to pedestrian access and proximate parking. Limited retail sales, showroom, or administrative offices may be located at the front of the tenant bay. The utility or service side of the bay is accessed from a vehicular service drive. Service drive pavement dimensions are sized relative to the type of service vehicle required for the targeted tenant group. While smaller delivery trucks can be accommodated in as little as 45 feet, docking and circulation widths generally range from 85 feet to 130 feet for larger vehicles. Individual or shared loading docks or service doors generally extend along the service facade proximate to interior bay storage, fabrication, or assembly operations.

While buildings are normally single story on slab construction, full or partial second stories (mezzanine levels) may be incorporated into the building. Upper levels are commonly devoted to administrative uses and often are limited to the front module of the building, leaving the areas above the utility portion or rear of the building with a higher ground-to-ceiling height, normally 14 to 20 feet. The type and flexible size of tenant space, upscale facade treatments, and overall site finish associated with facilities of this type are attractive to a diverse range of tenants, which may include such uses as bulk warehouse, industrial/office, light manufacturing, office/showroom, research and development, and retail service centers.

Lot coverage and floor area ratios vary according to local regulations and size and bulk requirements of principal user groups. Generally, larger users command higher coverage and FAR capacity owing to the magnitude of desired floor plate and associated reduction in employee and customer parking needs. A reasonable range in smaller flex-tech and office-showroom combinations may be between 0.24 and 0.35 FAR. Figures 11.25 and 11.26 illustrate the flex-tech building and portion of a flex-tech park, respectively.

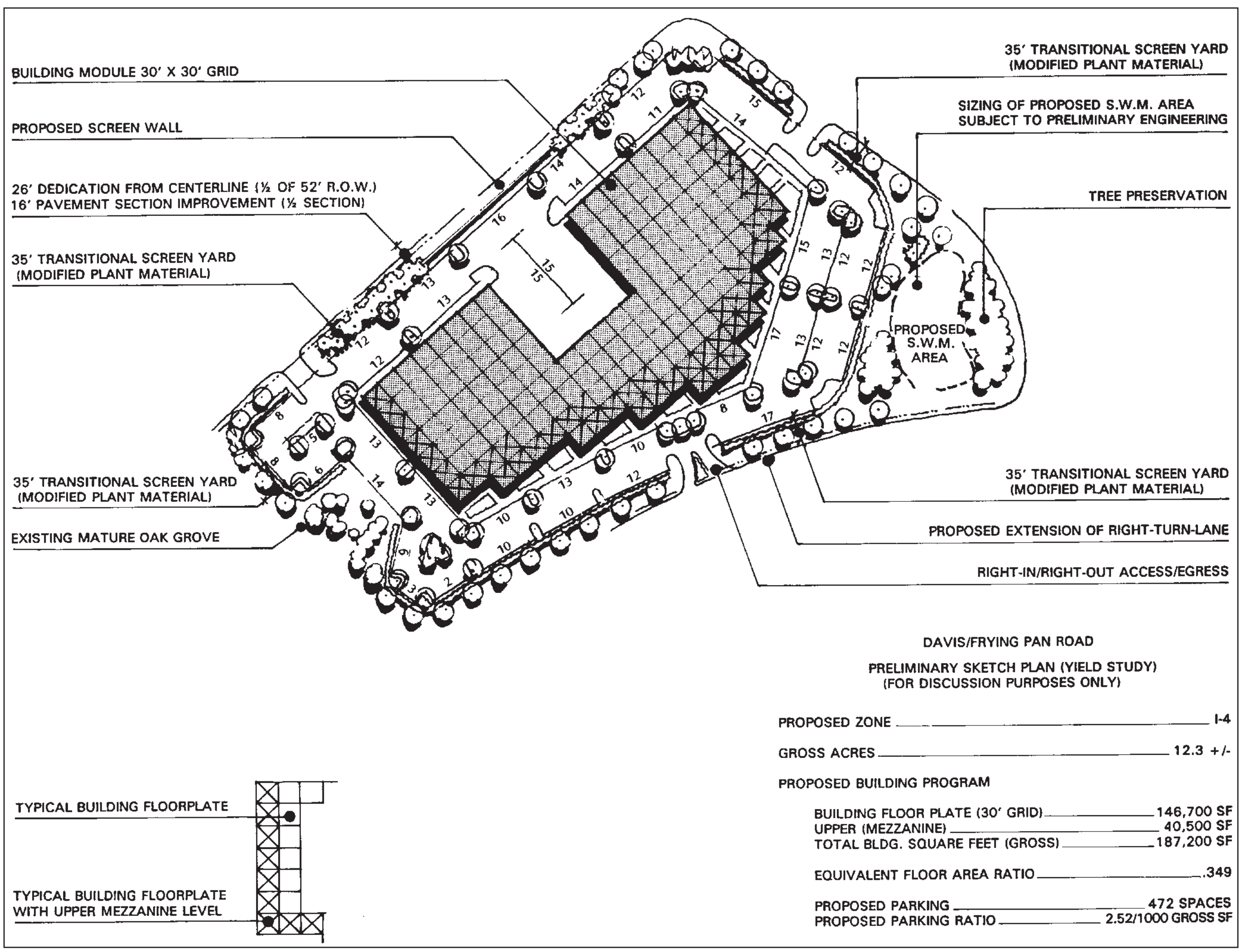

FIGURE 11.25 Example flex-tech building.

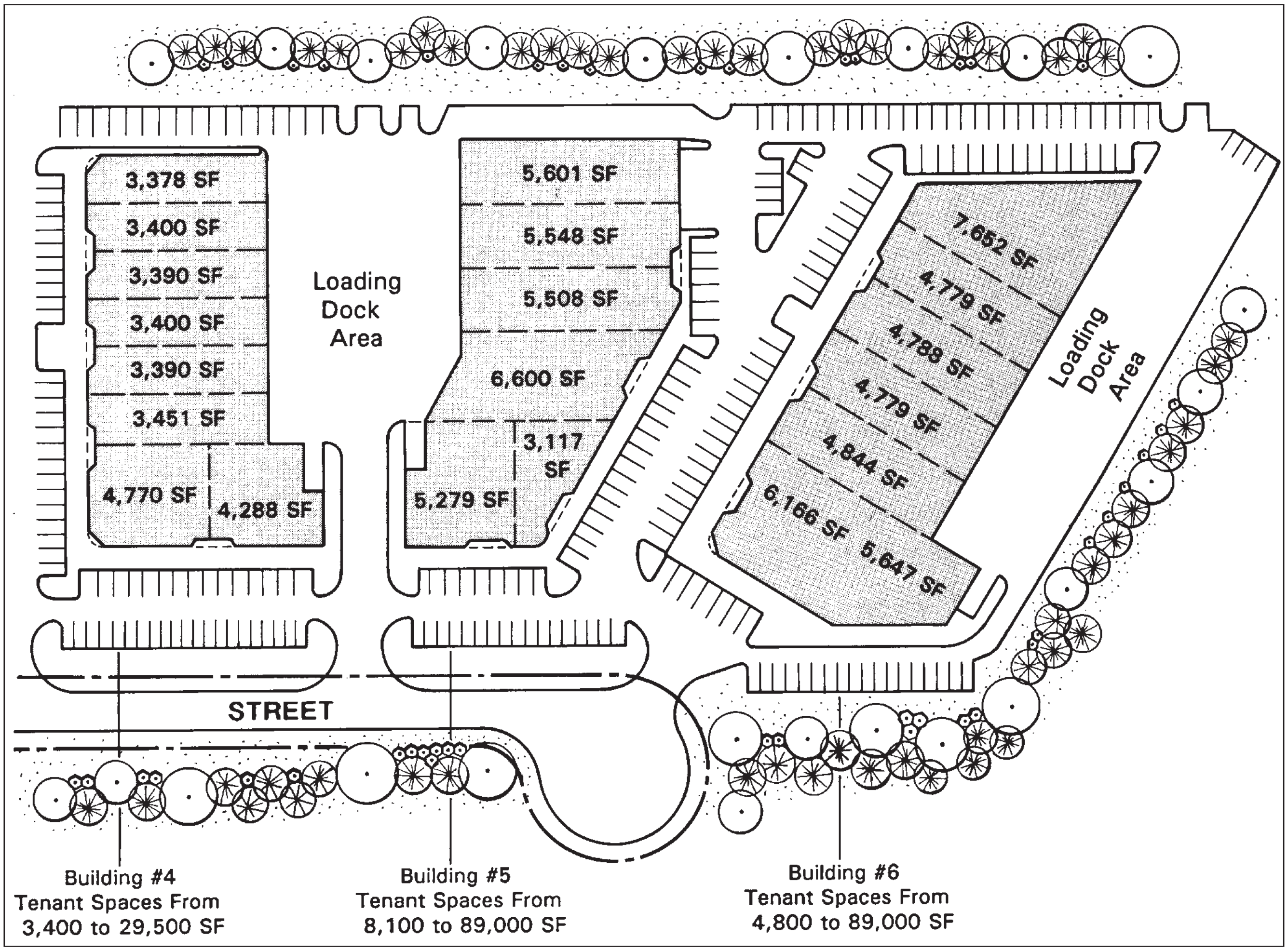

FIGURE 11.26 Example flex-tech park.

CONCLUSION

Response to contemporary development trends, particularly in the suburban context, has fostered much introspection in regard to both the quality of life and the environment. While the development of land on a project-by-project basis will in all likelihood not abate, greater integration of uses internal to individual developments or within the larger community context is increasingly evident in our built environment.

Both new market opportunities and community planning initiatives that seek to better direct and control the location, content, and quantity of development have fostered this attitude.

Numerous factors have occasioned a renewed look at development market opportunities and, in turn, development composition and project content. Increasing land costs have encouraged movement toward an increase in development densities. The level of vehicular congestion has prompted more deliberate evaluation of development opportunities proximate to mass transit facilities or in closer proximity to supportive land uses, which might minimize reliance on the automobile or shorten travel time. Increased popularity of a greater variety of leisure activities, coupled with shifting demographics toward smaller families, empty nesters, and single-occupant households prompts evaluation of requisite yard requirements, the venue of project amenity provisions, and proximity to existing and proposed community institutional and cultural offerings.

Public initiatives, in attempting to come to terms with the public infrastructure required to support future development activity, have similarly focused on efforts to mitigate the current dependence on the automobile as the principal mode of transportation. Efforts to promote mass transit, concentrate development density near existing and planned transportation corridors, and integrate a variety of residential, retail, and employment uses with greater reliance on pedestrian travel all attest to the prospect for less insular, more integrated land development patterns.

Emerging trends that have implications on the content and context of development patterns and principles include the following:

- A greater focus on the integration of uses as might be exhibited in a reduction in distances between development types, or vertical integration as with first-floor retail and upper-level office or residential uses

- An increased mix of uses, from the standpoint of an increased variety of residential types, given the market diversity of residents, as well as potential for greater integration of nearby retail and employment activities
- A renewed focus on the connectivity within and between developments both in the context of ensuring adequate and alternative means of vehicular movement and in greater attention to pedestrian opportunities
- A reassessment of the location and positioning of open space with recognition of its role in place making and elevating it beyond the unusable or leftover ground within a development
- Increased attention to building placement, massing, and scale as tools in defining space, directing views, and encouraging diversity in the pedestrian experience
- A reassessment of the nature, magnitude, and placement of parking in terms of (1) potential for joint use and parking reductions owing to use adjacencies, (2) increased reliance on integral parking or parking structures in response to increased land cost, and (3) potential relegation of parking from forefront to rear yard as buildings move street-side
- Continued evaluation of the hierarchy and configuration of street networks, recognizing the need for safe and efficient vehicular movements, as well as enhanced pedestrian opportunity and experience
- Integration of environmentally sensitive practices driven by LEED and other green building guidelines, low-impact development, and sustainable design technologies

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PART IV

SCHEMATIC DESIGN

INTRODUCTION

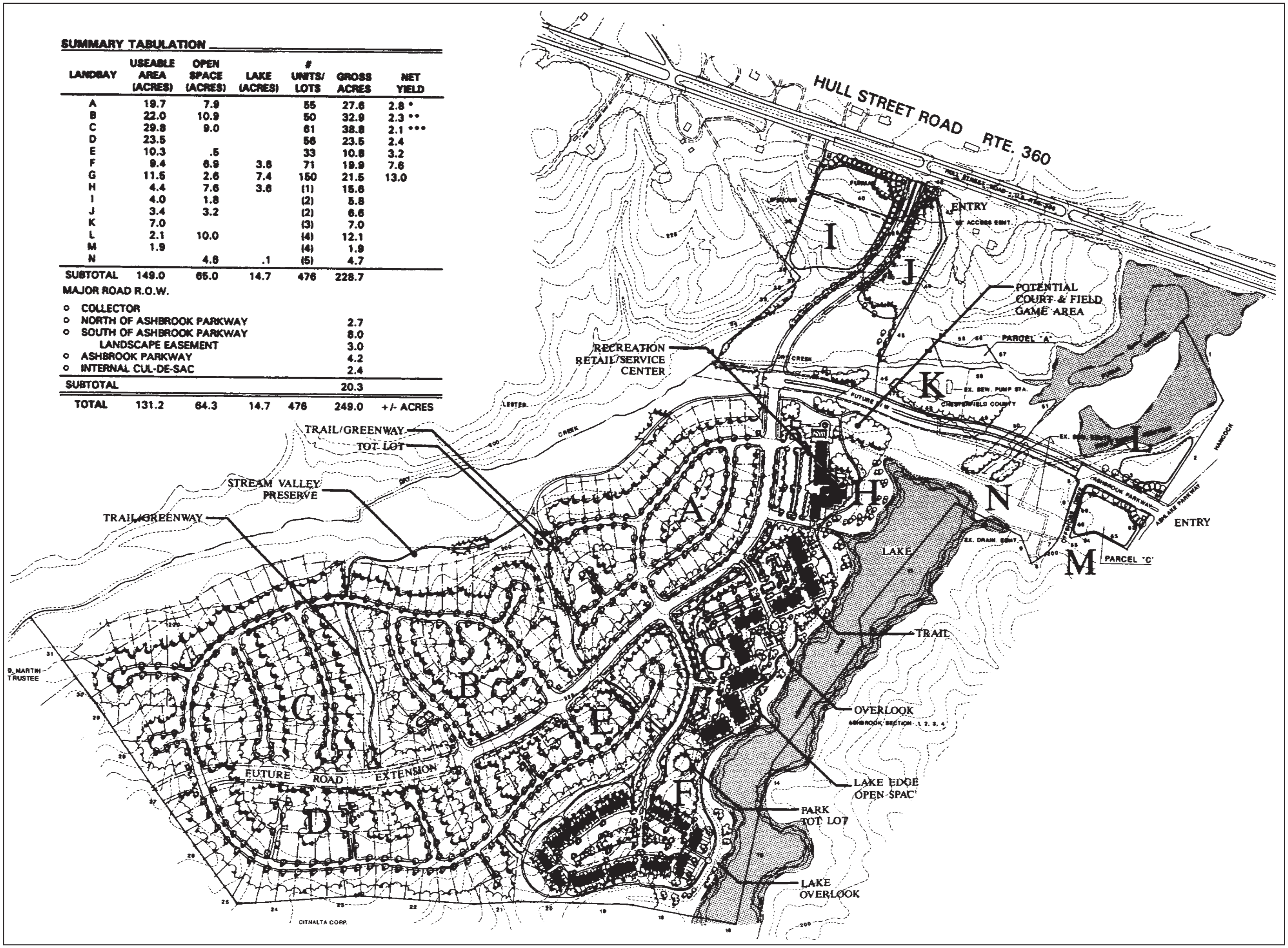
Schematic design focuses on the development and refinement of the concept design and results in an interim blueprint for subsequent detailed design efforts. During this phase of study, a selected concept plan is subjected to more detailed analysis in terms of usable area and potential yields. Activity may include a formal presentation to public bodies and regulatory agencies to obtain concurrence with the site design strategy. This phase represents a major benchmark in the design process in its testing and confirmation of development intent. In view of the increasing complexity of the public review process and the costs associated with more detailed design, public review at this phase of the land development design process is extremely important. It is a sound business practice to keep public decision makers abreast of a development proposal whenever practical. If there are to be political or procedural obstacles to the plan, it is best for them to surface early in the design process. Jurisdictions increasingly require various types of interim submissions prior to the completion of final site plan documents: schematic-level designs are not uncommon requirements for public-sector review and approvals.

STEP 4: SCHEMATIC DESIGN

The schematic or master development plan is the design document that establishes many of the controlling standards and design characteristics for actual project-level development. Extensive studies are normally completed to ensure that the proposed development program is realistic in terms of density, product yield, functional prerequisites, and environmental, economic, and political feasibility. Furthermore, the relative placement of land uses and infrastructure considerations begins to prescribe the ultimate project character or sense of place. The additional level of specificity provided in the schematic level of study includes:

- *Base mapping:* Refine initial mapping by producing or procuring accurate base mapping including a boundary survey and topographic survey at a scale comparable to forthcoming final design documents. Most jurisdictions require 2-foot or even 1-foot contour intervals for more detailed design efforts.
- *Environmental considerations:* Assess possible impacts on previously identified sensitive areas and coordinate preservation, restoration, or mitigation efforts with site design. Sustainable design strategies should be refined and optimized as infrastructure systems are implemented with increased detail.
- *Traffic and transportation:* Check the adequacy of the existing and proposed road system. Identify required transportation improvements in context of the site.
- *Utilities:* Preliminary sizing and routing of utilities should be provided.
- *Stormwater management:* Based on the impervious cover projected, preliminary sizing and location of stormwater management facilities can be determined.
- *Constructibility review:* Determine any phasing requirements that might impact further site design and develop a permit schedule for site, building, and environmental permits.

This refined level of information offered by other development team members affords the designer the opportunity



SUMMARY TABULATION

LANDBAY	USEABLE AREA (ACRES)	OPEN SPACE (ACRES)	LAKE (ACRES)	# UNITS/ LOTS	GROSS ACRES	NET YIELD
A	19.7	7.9		55	27.6	2.8 *
B	22.0	10.9		50	32.9	2.3 **
C	29.8	9.0		61	38.8	2.1 ***
D	23.5			56	23.5	2.4
E	10.3	.5		33	10.8	3.2
F	9.4	6.9	3.6	71	19.9	7.6
G	11.5	2.6	7.4	150	21.5	13.0
H	4.4	7.6	3.6	(1)	15.6	
I	4.0	1.8		(2)	5.8	
J	3.4	3.2		(2)	6.6	
K	7.0			(3)	7.0	
L	2.1	10.0		(4)	12.1	
M	1.9			(4)	1.9	
N		4.6	.1	(5)	4.7	
SUBTOTAL	149.0	65.0	14.7	476	228.7	
MAJOR ROAD R.O.W.						
o COLLECTOR						
o NORTH OF ASHBROOK PARKWAY					2.7	
o SOUTH OF ASHBROOK PARKWAY					8.0	
LANDSCAPE EASEMENT					3.0	
o ASHBROOK PARKWAY					4.2	
o INTERNAL CUL-DE-SAC					2.4	
SUBTOTAL					20.3	
TOTAL	131.2	64.3	14.7	476	249.0	+/- ACRES

FIGURE IV.1 Example of schematic development plan.

to perfect the schematic plan in terms of the allocation of areas suitable to accommodate infrastructure requirements as well as resolve any conflicts that have been identified during this review and assessment activity. The end product of the schematic design phase is a scaled representation of the development program and circulation framework (see Figure IV.1). Major elements normally include:

- Major vehicular circulation systems depicted in conformance with the design standards of the local jurisdiction and current comprehensive or master planning considerations.
- The allocation of land uses annotated by use and area. Area is normally noted as the gross acreage of the individual land units commonly referred to as *landbays.*
- Identification of areas subject to development constraints, including floodplains, wetlands and environmentally sensitive areas, buildings or grounds considered historically significant, and other acreage that by virtue of unique circumstance has been mandated by public policy to be subject to development limitations.
- Appropriate delineation of areas for public facilities, including schools, public safety, libraries, parks and recreation facilities, day care centers, church sites, and similar facilities that have been determined to be necessary or desirable support components of the initial development program.

Base Map

For site design, a base map (see Figure IV.2) that details the property configuration and terrain is a fundamental requirement. Property limits, from either a field-run property survey, research and plotting of existing deeds and records, or available parcel tax maps, together with topographic information constitute the primary elements of the base map. This information should be augmented with secondary information including such items as road rights-of-way/pavement widths, existing structures, vegetation, bodies of water, streams, adjacent property boundaries and surrounding parcels, and utility rights-of-way and easements.

Despite the variety of technologies available to enlarge base materials, it is preferable to work with information that was

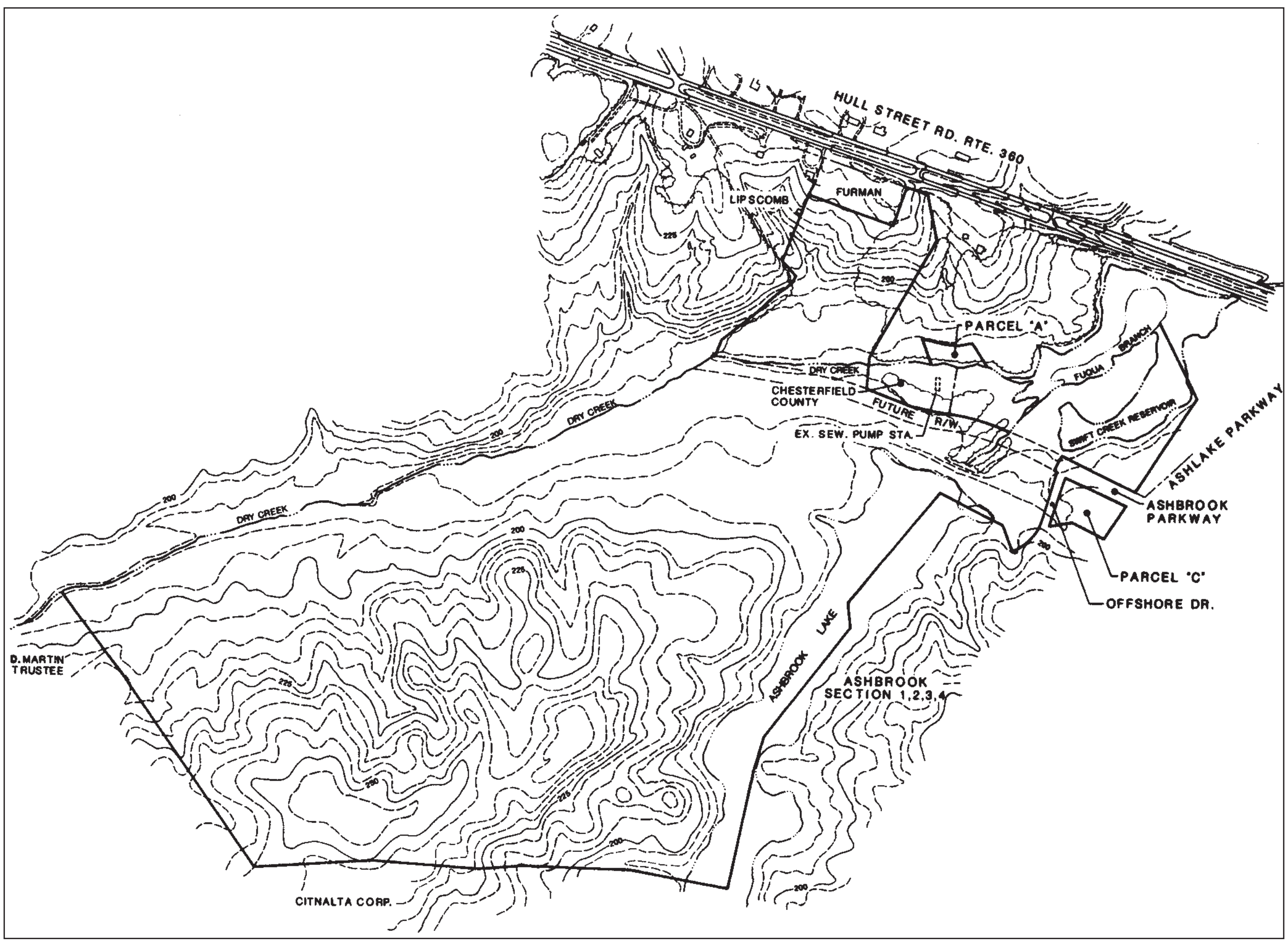


FIGURE IV.2 Example of a base map.

originally compiled at a scale close to that which the designer is using in his or her studies. The scale of a base map may vary depending on both the size of the subject property and recognition of ultimate plan submittal requirements necessary as part of a public review and approval process. While there are many reasons for selecting a particular scale for the base map, one should never lose sight of (1) the need for the base to satisfy public submission requirements and (2) a scale that is consistent with the designer's need to present a level of accuracy in reviewing the various development considerations.

PART IV.A. BASE MAP PREPARATION

CHAPTER 12

CONTROL SURVEYS FOR LAND DEVELOPMENT

Joseph W. Betit, PLS

INTRODUCTION

Since the second edition of the *Land Development Handbook,* there has been an astonishing transformation in the equipment available to land surveyors, including robotic reflectorless electronic distance meter EDM total stations equipped with integrated global positioning systems (GPS), digital self-reading levels, terrestrial laser scanners, GPS real-time networks, and GPS-controlled construction machinery.

Alongside these equipment advances, survey accuracy standards have shifted to three-dimensional geospatial positional standard error formats. To support these new accuracy standards, least squares adjustment software for survey data of all types is now commonly available and is very robust in its handling of problematic data sets, negating any reason to use prior adjustment methods such as the Crandall rule. In fact, least squares adjustment of data is required as a best practice for ALTA/ACSM boundary surveys as well as all GPS data processing and the integration of multiple terrestrial laser scan point clouds.

The land surveyor establishing survey control of *appropriate quality* that encompasses the entire land development project, including all current and future phases, has the following key objectives to support with the control:

- Ground and aerial topographic mapping of existing physical features within the tract, as well as any external areas influencing the permitting process.
- Boundary recovery, determination, and monumentation.
- Construction stakeout: *Practically, the level of accuracy of the survey control is determined by the accuracy needs of the infrastructure that is to be built if it contains steel or concrete structures.*
- Postconstruction as-built surveys and certifications.
- Legal defensibility of all positioning provided by the surveyor.

The elements of establishing survey control that are discussed in this document are ultimately only guides that assist in the effort to achieve the project goals. Project survey control is a complex and fascinating aspect of modern land development in which there is a great deal of science and art involved that often requires significant professional judgment. Good project economics dictates that all elements of the control should be sufficient to the task and yet still meet the expectations of best practice within the local professional surveying community. See Figure 12.1.

The backbone of any land development project is the control network. From inception to completion, the success of a project depends on accurate horizontal and vertical control. Project designs, as well as staking for construction, are based on the boundaries and topography established by the survey of the property. If the accuracy of the horizontal and vertical control is poor, the consequences can be disastrous.

Because all measurements contain a certain amount of error, surveyors must apply corrections and adjustments to remove the inevitable misclosures in traverses and level loops in their survey measurements. Such adjustments allow surveyors to evenly distribute these inevitable errors found in survey measurements. The accuracy of the work is completely dependent on how the surveyor deals with these errors in measurement. One method of evaluating the qual-

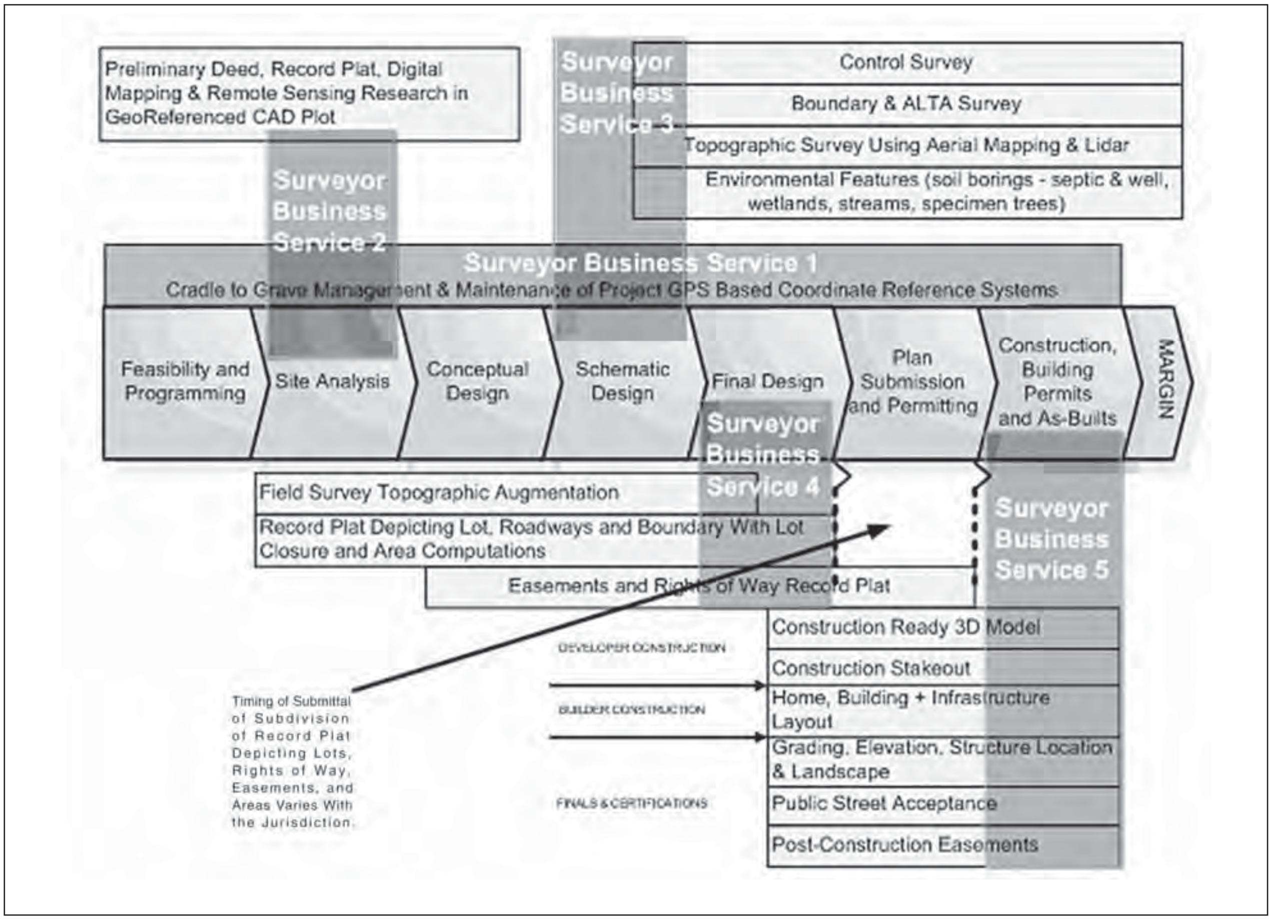


FIGURE 12.1 Surveying services and the land development process.

ity of a surveyor's work is to compare it to industry standards, which are based on detailed specifications. Such specifications also give surveyors the means to evaluate the quality of their survey equipment. If the accuracy of the equipment is known or can reasonably be estimated, the adjustment of horizontal and vertical control work can be properly performed. Surveyors must be aware of the relationship among standards, specifications, and adjustments as well as how standards and specifications control the proper conduct of fieldwork. At the end, the least squares method of adjustment of conventional survey data is discussed. This method allows the land development surveyor to simultaneously incorporate standards and specifications, errors, and adjustments to provide the best estimate of the true position of the objects being located.

Classic geodetic control surveying, such as triangulation, has been supplanted by the U.S. Global Positioning System (GPS) satellite technology, and satellite surveying continues to evolve with the addition of the Russian GLONASS system and the European system (Galileo). The entire constellation of various satellite systems is now being referred to as the Global Navigation Satellite System (GNSS). The geodetic level of precision measurements resulting from the use of GNSS equipment does require that the land surveyor be aware that it is now possible to detect such matters as long-term land subsidence over large regions. GNSS has put much of the benefit and accuracy of geodetic surveying within the reach of licensed surveyors supporting land development and has greatly extended their capabilities to serve their clients.

Beyond the changes in measuring technology, survey data must increasingly comply with new three-dimensional positional accuracy standards. This evolution has been driven by the need to produce products that integrate digital geospatial data such as spaceborne digital imagery, digital orthophotos, GIS data, digital terrain models, and LiDAR (light detection and ranging) laser point clouds, both airborne and terrestrial.

Another impact of the use of satellite positioning systems results from their coordinates being based on a global coordinate system. A surveyor using GPS equipment can travel anywhere in the world and carry out a survey in this global system of coordinates. This has resulted in the rapid emergence of cooperative international spatial accuracy standards and work specifications shared by surveyors across national boundaries.

IDENTIFY THE HISTORY OF PRIOR PROJECT CONTROL

Following in the Survey Control Footsteps of Previous Project Surveyors

Survey control for subdivision development in the United States from the late 1800s well into the 1980s was often carried out in a nongeodetic, assumed origin, plane coordinate system. In such cases the boundary survey traverse control was carried out with engineering transits, optical theodolites, and digital total stations that were used to recover and set the boundary based on an assumed coordinate system that also ultimately became the project horizontal control. The project Basis of Bearing for the horizontal control was usually based on holding one of the record plat bearings between a pair of recovered project boundary monuments.

For subdivision vertical datums, a point was often set in a safe location (a railroad spike in a power pole was normal) near the project and designated as the project benchmark, with an assumed elevation assigned to the benchmark. This elevation was often denoted as "100.00 feet," even though the elevation estimated from a government contour map would have been quite different. There was logic in this in that it was usually hard to mistake plan elevations expressed in the project vertical datum for true elevations.

Wherever there was aerial mapping for a project, the project surveyors usually took the vertical datum much more seriously and carried out differential leveling to transfer a published elevation from the closest suitable government benchmark. Whether the vertical datum was assumed or based on published information for a vertical benchmark, the vertical control station elevations are almost certain to be based on differential leveling because trigonometric leveling capabilities were often inadequate for project vertical control.

With the advent of high-precision self-compensating total stations in the mid-1990s, some highway project vertical control carried out by trigonometric methods began to emerge. This form of leveling has become more common in private development projects as high-precision digital total stations have become more common; however, regional differences in the acceptance as best practice of trigonometric versus differential leveling must be taken into consideration.

Prior to the 1980s some urban centers of the United States had an official horizontal coordinate system and a vertical datum realized in a network of control monuments and benchmarks that development projects could be tied to. For instance, the Los Angeles city control system was begun well before World War II. Local regulations in such areas contained the caveat that the official system was to be used only if the distances from the project were not so large as to make the land development surveyors' control work uneconomical if they attempted to base their work on official monuments.

The project surveyor setting up project control for a modern project that ties to older projects must understand the difference in approaches between the two eras of project surveying that can be best expressed as nongeodetic versus geodetic.

Geographic Information Systems (GIS) and Modern Survey Control

In the late 1980s during the advent of GIS, the early stages of state and municipal GIS mapping implementation were crude affairs and primarily intended for use by planning and tax assessor departments. The early GIS maps were frequently conceptual in nature and much distorted when compared to the surveyors' mapping.

Over time, increasing demand for more accurate GIS mapping drove the development of more precise control for GIS mapping. These systems usually were established with the aid of classical GPS static baseline surveying and some differential leveling. Survey control from the early era of GIS varies in quality due to the very rapid evolution of the quality of the national survey control system since the early 1990s.

IDENTIFY YOUR LOCAL AGENCY DATUMS REGULATORY REQUIREMENTS

The land development surveyor has to be aware of the different agencies and their survey control requirements that can have an impact on the project. The standards of these agencies are also a good resource for designing and setting specifications for the project survey control. It takes considerable time to develop effective specifications, so it makes economic sense to adopt well-thought-out existing documents wherever possible. Here is a basic list of sources of control survey classifications and orders. City and county specifications are also useful and tend to be enhancements of or derivatives of the following entities:

- Federal Conventional Survey Horizontal Classifications and Orders
- Federal Conventional Survey Vertical Classifications and Orders
- Federal Global Positioning System (GPS) 3D Survey Classifications and Orders
- U.S. State Highway Department GPS 3D Survey Classifications and Orders
- U.S. State Highway Department Conventional Survey Classifications and Orders
- U.S. Private Land Title and Boundary Survey Accuracy Requirements—ALTA/ACSM

Survey Control Metadata (Data Lineage)

The first step in using National Geodetic Survey (NGS) or other published control stations selected for the basis of surveys must be a careful compilation of the metadata for the critical stations. This metadata must include the following:

- Survey order and order class
- Survey methodology used to establish the control
- History of NGS network adjustments existing at the time of the GPS survey
- History of changes in horizontal and vertical datums and in corresponding coordinates
- Subsequent remeasurements and readjustments

These elements must be carefully documented and considered prior to using local or federal agency control systems.

Horizontal Control System Coordinate Datums. The horizontal coordinate systems used by surveyors to establish survey control for agencies are usually selected from one of the NGS State Plane Coordinate System geodetic map projections (1927 or 1983) or NGS Universal Transverse Mercator Zones. There is a specific State Plane Coordinate System designed for each state, which has subsequently been incorporated into state law as the approved state coordinate system by the state legislature (see Appendix A, "Aerial Mapping and Surveying," for additional information on State Plane Coordinate Systems and map projections).

Vertical Control Datums. The vertical datum is frequently defined as one of the NGS national (engineering and mapping focus versus tidal) vertical datums. Sometimes it is the older 1929 National Geodetic Vertical Datum (NGVD27), but increasingly it is the modern 1988 North American Vertical Datum (NAVD88). These engineering vertical datums are designed to span the entire continent with a uniform vertical datum suitable for mapping and infrastructure design.

It is critical for the surveyor to understand that these engineering datums usually do not match local sea level on the coasts of the seas, bays, and the Great Lakes. Corrections based on ties of the engineering datum to local water height monitoring stations must be made for coastal design work. In addition, the surveyor should be aware that it is not uncommon to find agency-specific assumed vertical datums, especially in older coastal cities, that are not a part of the national datum definitions. (See Appendix A for additional information on State Plane Coordinate Systems and map projections).

Areawide (city, county, regional utility) differential-leveling campaigns carried out by survey field crews are very expensive because of the time needed to walk all the distances between monuments multiple times. Due to the high labor expense associated with differential leveling, the vertical component of an agency network is almost always the weakest link in the system because of inadequate budgets for the work. When using modern GNSS surveying, this weakness becomes very apparent and can require difficult professional decisions on how to handle vertical benchmark discrepancies that persist through the life of the project. There are different approaches to this problem, which will be discussed later in this chapter.

Vertical datum shifts, especially easy to propagate with the advent of high-precision GNSS-based survey control, are an important source of error in development projects. This is especially true when tying two disparate projects together or when a subsequent project phase is started years later. *Project vertical datum errors are often economically catastrophic for a development project and must be guarded against continually by the project surveyors.* Projects with multiple datums are best served by including a nomograph (diagram) on the project plan set.

NGS Ellipsoid Models. There are two NGS ellipsoids used for the latitude and longitude determinations of the national control networks. The 1927 datum is based on the 1866 Clarke Ellipsoid, which is a surface fit (mean sea level), continental geoid model. The 1983 datum is based on the GRS80 global fit (earth centric) ellipsoid, which at the time of its formation was very nearly equal to the WGS 84 ellipsoid. All GNSS measurements in the United States are made in the WGS84 definition (see Appendix A for additional information on State Plane Coordinate Systems and map projections).

The older 1927 datum contains many distortions and there is not a precise, known relationship, between the 1927 and 1983 datums. Free software developed by NGS and the U.S. Corps of Engineers such as CORPSCON can perform mapping accuracy transformations between the two systems, but the transformation accuracies are not suitable for precise surveys.

Geoid Models and Orthometric Heights (Elevations). One of the most elusive concepts to master for the modern surveyor first starting to use GPS is the geoid model and its relationship to orthometric height. From the practical perspective of the land development project surveyor, the elevations used in the project are equivalent to what the NGS terms the *orthometric height.* Classical differential leveling is carried out in the local gravity field. GPS uses a national gravity model called the *geoid model,* which closely models the variation in local gravity fields across the entire continent. This model corresponds closely to the national engineering datum NAVD88. (See Appendix A for additional information on State Plane Coordinate Systems and map projections.)

GNSS locates a position on the WGS84 ellipsoid, which is a mathematical model of the earth and then uses the geoid model assigned in the processing software along with the height of the GNSS receiver antenna to develop a best estimate of orthometric height (elevation) at the position measured. There can be significant differences between the GNSS elevation derived from its two models of the shape and gravity of the earth and the differentially leveled elevation measured on-site. These differences are critical for the land development surveyor to understand, define in writing, and have well-thought-out and implemented procedures for verification and calibration of the GNSS-based elevations to the leveled information.

The flow of water is dictated by gravity—not by ellipsoid and geoid models! The results of local leveling are more certain than GPS of producing correct elevations, and the project surveyor must keep this in mind at all times when substituting GPS-based elevations for leveled elevations. Caution, regular checking of known positions, and common sense about the elevations being provided by GNSS units are essential to avoiding elevation problems in projects, especially in the case of hydraulic grades for storm drain and sewer infrastructure.

Land surveyors working on a development project should expect to have to comply with local agency survey horizontal coordinate and vertical datum requirements. If these do not exist, wise surveyors will use GNSS equipment and methods to establish appropriate modern NAD83 State Plane coordinates and NAVD88 elevations for the project. From these, a shift can be made to any other coordinate or vertical datum system if the need arises, but at least the surveyors will be assured their project is already in a modern datum if the official requirements of the local agency should change in the future, stipulating the use of a modern coordinate system. The work will already have been accomplished and no disruption in the project will occur due to newly mandated horizontal and vertical datum shifts.

Determine Agency-Required Survey Specifications and Accuracy Standards

For many decades the NGS developed and maintained accuracy standards and survey specifications for field procedures that would achieve those accuracy standards. (See Table 12.1.) These standards were based on the use of con-

TABLE 12.1 Accuracy Standards and Survey Work Specifications

U.S. National Control Survey Accuracy Standards

1. Federal Geographic Data Committee (FGDC) Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques (Version 5.0, 1989)
2. FGDC Geospatial Positioning Accuracy Standards
   a. FGDC-STD-007.1-1998 Part 1: Reporting Methodology
   b. FGDC-STD-007.2-1998 Part 2: Standards for Geodetic Networks
   c. FGDC-STD-007.3-1998 Part 3: National Standard for Spatial Data Accuracy
   d. FGDC-STD-007.4-2002 Part 4: Architecture, Engineering, Construction, and Facilities Management
   e. FGDC-STD-007.5-2005 Part 5: Standards for Nautical Charting Hydrographic Surveys
   f. FGDC-STD-008-1999 Content Standard for Digital Orthoimagery
   g. FGDC-STD-009-1990 Content Standard for Remote Sensing Swath Data
   h. FGDC-STD-010-2000 Utilities Data Content Standard
   i. FGDC-STD-011-2001 Standard for a U.S. National Grid
   j. FGDC-STD-012-2002 Content Standard for Digital Geospatial Metadata: Extensions for Remote Sensing Metadata

U.S. National Mapping Accuracy Standards

3. National Map Accuracy Standards (NMAS 1947)
4. National Standard for Spatial Data Accuracy (NSSDA)
5. American Society for Photogrammetry and Remote Sensing (ASPRS) Standard for Large Scale Maps (ASPRS 1990)
6. ASPRS LiDAR Guidelines Vertical Accuracy Reporting for LIDAR Data

U.S. Land Title National Survey Accuracy Standards

7. American Land Title Association (ALTA/ACSM) ALTA Accuracy Standards
8. U.S. Forest Service and U.S. Bureau of Land Management Standards and Guidelines for CADASTRAL SURVEYS Using Global Positioning System Methods (version 1.0, May 2001)

U.S. State Highway Control Survey Accuracy Standards

9. Various U.S. State Highway Department Survey Standards
   a. GPS 3D Survey Standards
   b. Conventional Survey Standards

International Control Survey Accuracy Standards—Specific National Applications

10. Australia Inter-Governmental Committee on Surveying and Mapping Standards and Practices for Control Surveys (SP1 version 1.5, May 2002)

ventional survey instruments (transits, theodolites, digital total stations, differential levels, calibrated steel measuring tapes, electronic distance meters) operating in triangulation and traverse modes. These standards were separated into horizontal and vertical components.

Shortly after the introduction of the 1983 NAD, GPS entered the scene and the NGS standards rapidly began to evolve to adjust to the new technology. By the late 1980s, the entire 1983 NAD network adjustment was in flux as transcontinental GPS campaigns were initiated in an effort to drive network distortions below 1 meter from coast to coast.

The fundamental difference between prior survey methods and GPS is that GPS is a true 3D system. This means that the vertical component of the measurement is an integral part of the network least squares adjustments. New NGS 3D positioning accuracy standards were developed under the auspices of the Federal Geodetic Data Committee (FGDC). Also developed were static baseline GPS survey specifications designed to ensure that the accuracy standards were achieved. However, with the advent of real-time kinematic (RTK) GPS surveying, surveyors have entered a decade-long period of uncertainty about proper survey specifications. RTK is subject to many variables that are removed in baseline survey processing. Achieving a reliable set of survey specifications that guarantee meeting specified accuracy standards has been very difficult.

Surveyors may not see reliable RTK specifications until the entire constellation of GNSS (GPS, GLONASS, and Galileo) is in place over the next decade. The full constellation would provide the positioning assets necessary to overcome signal multipath and satellite signal loss from obstructing buildings, trees, and so on.

HOW TO HANDLE THE MULTIPLE COORDINATE SYSTEMS CHARACTERISTIC OF REGIONAL INFRASTRUCTURE PROJECTS

Industrial-style enterprises, such as a large metropolitan transit system, may overlay multiple agency coordinate systems and may have a unique systemwide coordinate and vertical datum system. It is not uncommon for urban redevelopment projects to involve multiple agency coordinate systems.

In such cases, the use of GNSS to establish project survey control is especially advantageous to land development surveyors. The GNSS systems employ World Geodetic System 1984 (WGS84) ellipsoid coordinates. From this unified, global coordinate system, it is relatively straightforward for land development surveyors to perform horizontal coordinate shifts across regional projects of any real extent in order to match local agency coordinates as necessary. GNSS is a critical tool for the project surveyor whose land development project adjoins such regional industrial enterprises.

DETERMINE PROJECT-SPECIFIC GEOSPATIAL ACCURACY REQUIREMENTS

In addition to agency accuracy standards and specifications, the project will have its own accuracy needs. The most straightforward way to determine project requirements is to look at a few critical components of the project, especially the hydraulic and concrete components.

Hydraulic Component

Stormwater and sewer have certain minimum grades that must be accurately maintained. The less terrain relief a project has, the more critical the vertical design constraints become for the engineers. In coastal regions, projects can be very constrained vertically due to the lack of elevation change over the site. The precision and density of survey terrain mapping and modeling are critical to a successful design in flat terrain. In addition, once the design is completed, survey vertical accuracy and precision during stakeout in flat terrain becomes critical to the success of the contractor in achieving the construction of the design.

Concrete and Prefabricated Structures

Other critical components to examine are those project elements involving concrete and/or the mating of off-site prefabricated components with on-site constructed components. Curb and gutter, critical building floor pads that are site controlling, and prefabricated bridges transported to the building site that must match cast-in-place concrete footings are examples of these different survey components.

Curb and gutter is placed in a variety of ways, and the survey requirements of the contractor dictate the accuracy of the surveying methods. Local knowledge of construction companies is invaluable here. It is not unusual for a land development site to have one or more critical building locations. The final cement pad heights set for these buildings can become, in essence, the survey control for the area around it. For instance, curb and gutter with concrete sidewalks built abutting the building may have to conform to a variety of criteria, all controlled by height down from and distance from the edge of the building pad. This naturally controls the heights of the road adjoining these structures. It is also common for metal structures such as pedestrian or golf cart bridges to be constructed off-site. The concrete and bolt mounting structures built on-site must match the preconstructed structure when it is delivered.

Advance knowledge of these issues impacting the expected survey accuracy during the planning stage are important to the design and execution of the initial survey control. The project surveyor is wise to exam these issues closely and design their survey control accordingly.

DESIGNING AND PLANNING THE PROJECT SURVEY CONTROL SCHEME

Once the most demanding accuracy components of the project are determined, the project surveyor can begin design of the survey. Project surveyors often design a survey in the form of interlocking hierarchies and subsystems of accuracies. Expensive higher-order control is established in the proximity of infrastructure anticipated to need it. A sparse network of precise control is often established well outside the perimeter of the project first. This is used for the aerial mapping and then further densified in the interior of the project. The exterior primary network is also a reserve for replacing destroyed or disturbed interior control as necessary.

A fundamental rule of control survey design is that the more precise the survey control, the higher the cost. The cost relationship is not necessarily linear. For instance, meeting a 0.10 U.S. survey foot (sft) vertical accuracy requirement across an entire project is relatively straightforward using modern GPS RTK equipment. This is not a costly accuracy standard to implement.

However, extending the horizontal and vertical accuracy requirement to 0.01 sft, as may be needed for a bridge support pylon such that it encompasses an entire site, would be astronomical in cost. For example, let us say that a 100-acre site could have control set by a one-person survey crew to meet 0.10-sft vertical requirements for $2000 using radio or virtual reference station (VRS) RTK methods. In contrast, achieving 0.01 sft across the project would not cost 10 times more ($20,000) but more likely would cost around $35,000 because all the work would have to be done by two- or three-person survey crews using high-precision total stations and digital differential levels. This style of survey is very intensive in crew time and, accordingly, very costly.

OVERVIEW OF GNSS METHODS

Surveyors have four general classes of GNSS surveying available to them: classical static baseline, NGS OPUS and OPUS-RS, radio- or cell-based RTK, and real-time network RTK. One of the most popular forms of RTN RTK is a methodology developed by Trimble, called the VRS (Virtual Reference Station) network solution (see Figure 12.2). As the developers of *the VRS network solution,* Trimble has a trademark on the term VRS. Today, however, the term VRS is used almost universally for various network configurations. A huge array of literature is available on the Internet for information on static baseline surveying. For NGS OPUS and OPUS-RS (rapid static) methods, surveyors are referred to the NGS OPUS website at www.ngs.noaa.gov/OPUS/. There is also an extensive array of literature available on the Internet for radio/cell RTK. At the time this book was published, the new NGS RTK Standards and Specifications should also be available to control surveyors over the Internet. GNSS RTK or VRS is the newest and least understood of the GPS methods at this time and is the focus of the GNSS surveying discussion in this chapter.

TYPICAL FORMS OF REAL-TIME KINEMATIC (RTK) GPS SURVEYING

Single Base Station Radio RTK with or without Repeater Radio

This type of survey is done using the dual-purpose base station/rover unit with built in 1-watt transmitter. The transmitter is capable of a maximum range of 1.5 miles in wide-open, flat terrain. Distances of 0.5 to 1 mile in more difficult terrain are common. Many small sites require only this configuration for carrying out radio RTK survey operations.

Single Base Station Radio RTK with One or Two (Max.) Repeater Radio(s)

Radio RTK operations covering larger areas, such as setting up a calibration box around a small town (e.g., 3-mile × 3-mile), or for those operations requiring more radio power, use the 35-watt Trimble 450 repeater radio that works in conjunction with the base receiver radio.

The repeater can be moved to a location in which it still connects with the base in order to extend the base signal out 3 to 5 miles farther. The repeater can be moved anywhere it is needed within range of the R8 during the course of the survey without affecting the base station once it is started. A maximum of two repeaters can be used in a single survey.

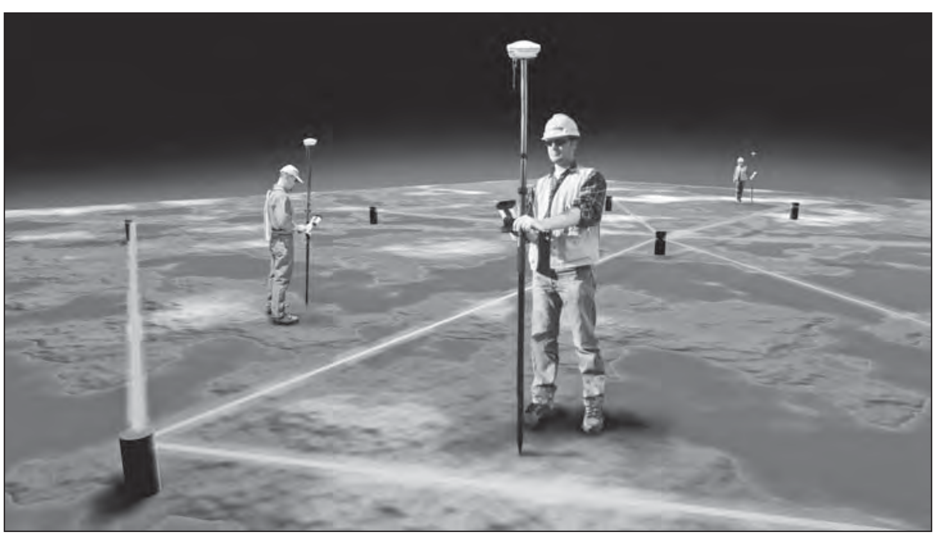


FIGURE 12.2 Conceptual diagram of Trimble VRS system showing multiple base stations and rovers. (Graphic courtesy of Trimble © 2008)

The second repeater is moved to its limits of connection with the first repeater, and it retransmits the first repeater's signal farther in order to continue the survey.

Multibase Network RTK

This approach uses cell phone connection to the Internet to access the VRS network provider. The network provides access to the nearest base station in the network for position corrections. It is similar to a single base station RTK operation but allows operation at much longer distances from the base station than radios permit. More than two repeaters cannot be used due to signal latency (delay), which causes the corrections transmitted from the base station to be out of synchronization with the satellite signals received at the rover.

Networked Base Station VRS RTK with Cell Phone

Corrections are provided resulting from the continuous processing of the data from multiple base stations. These corrections are transmitted to the rover over the Internet, using cell phone connections. The solution of multiple base stations requires that the Internet connections between the server and the base stations not have more than 2 seconds' latency (delay) in communications between them. Any base station delayed more than 2 seconds is temporarily dropped. The stations are reincorporated once the delay stops. The system still provides corrections, but they may not be as accurate as before the station drop.

Note: Communications latency when it occurs in radio, on the Internet, or due to poor cell phone reception are major sources of low-quality GPS RTK positioning—especially in network VRS.

HOW NETWORK RTK (VRS) AND SINGLE BASE RADIO RTK WORK AND THEIR DIFFERENCES

Ease of Setup and Better Security of Equipment

The current, modern radio RTK equipment is more compact than that shown in Figure 12.3, since it has fewer cables, but it still requires setting up your own base station. Base stations must be guarded or set in protected areas due to the increasing incidence of theft of unattended equipment.

In comparison with radio RTK, the VRS method relies on permanent base stations scattered across a region. All that is required is to set up the rover and log in over the Internet with a cell phone. The amount of equipment that has to be carried is minimal, and it is always with the operator in the field. (See Figure 12.4.)

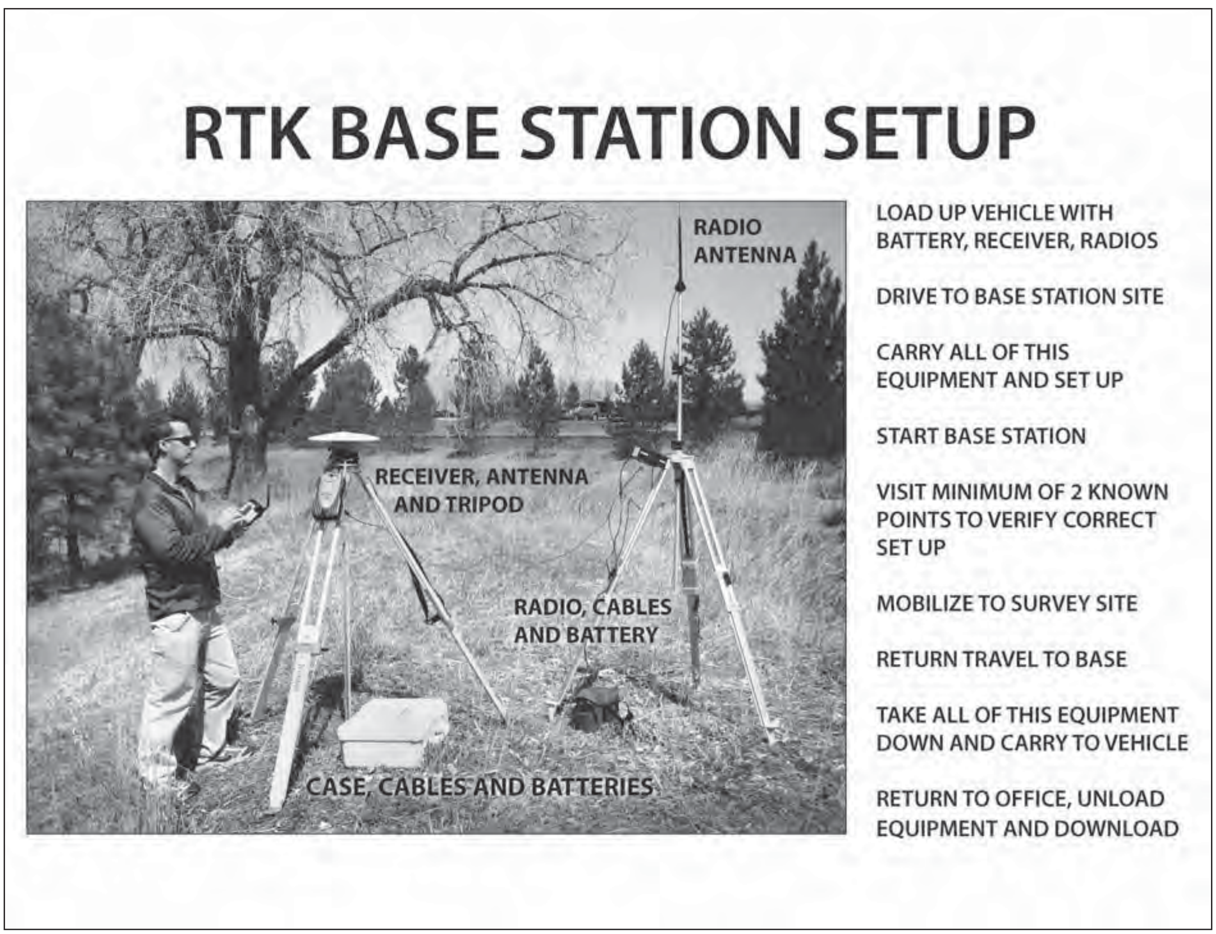


FIGURE 12.3 RTK base station setup. (Graphic courtesy of Trimble © 2008)

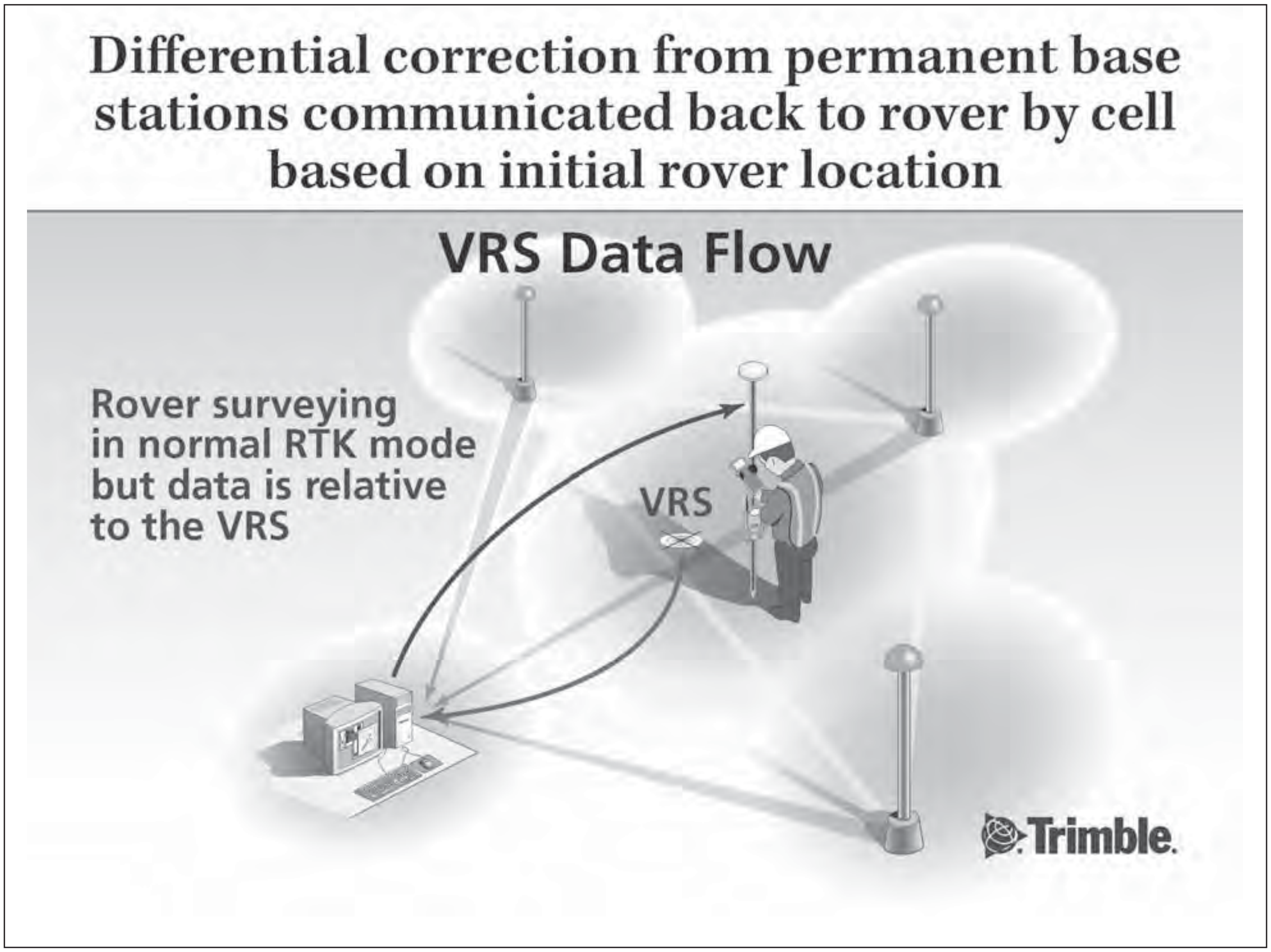


FIGURE 12.4 VRS data flow: differential correction. (Graphic courtesy of Trimble © 2008)

Range of Area of Operation of VRS versus Radio RTK

A radio RTK survey is restricted to operations within the range of the radio, which is usually an operating radius of 1 to 5 miles. A VRS survey can operate anywhere inside the reference base station network covering an entire region using the cell phone network to maintain connection with the network server. (See Figure 12.5.)

Accuracy

Both radio RTK and VRS RTK operate in a similar manner as the rover. The difference in the two methods is as follows:

- In radio RTK, a single base station only a short distance from the rover is used, which means *vertical positions tend to agree well with each other.*
- In VRS, multiple base stations are used to create an average correction for the rover. The base stations tend to be much farther away from the rover than in radio RTK. The result is that the *VRS verticals are much better over long distances than a single base station could produce but often have a larger spread than is usually the case with a single base.*

(See Figure 12.6.)

VRS is a type of wide-area RTK (WA RTK) system (Trimble definition). WA RTK systems consist of a distributed network of reference stations communicating with a control center to calculate GPS error corrections over a wide area. Real-time correction data is transmitted by radio or cellular modem to the rover receiver within the network area.

The system improves reliability and operating range by significantly reducing systematic errors in the reference station data. This lets you increase the distance at which the rover receiver can be located from the physical reference stations, while improving on-the-fly (OTF) initialization times. (See Figures 12.7 and 12.8.)

RECOMMENDED VRS POSITIONING PROCEDURES

In the Box

You must be aware of the VRS network boundaries. The best results are achieved when you work within the exterior limits of the VRS network (the box).

It has been found that satisfactory results can be achieved working up to 6 miles (10 km) outside the box, but it is not recommended procedure and network operators nor-

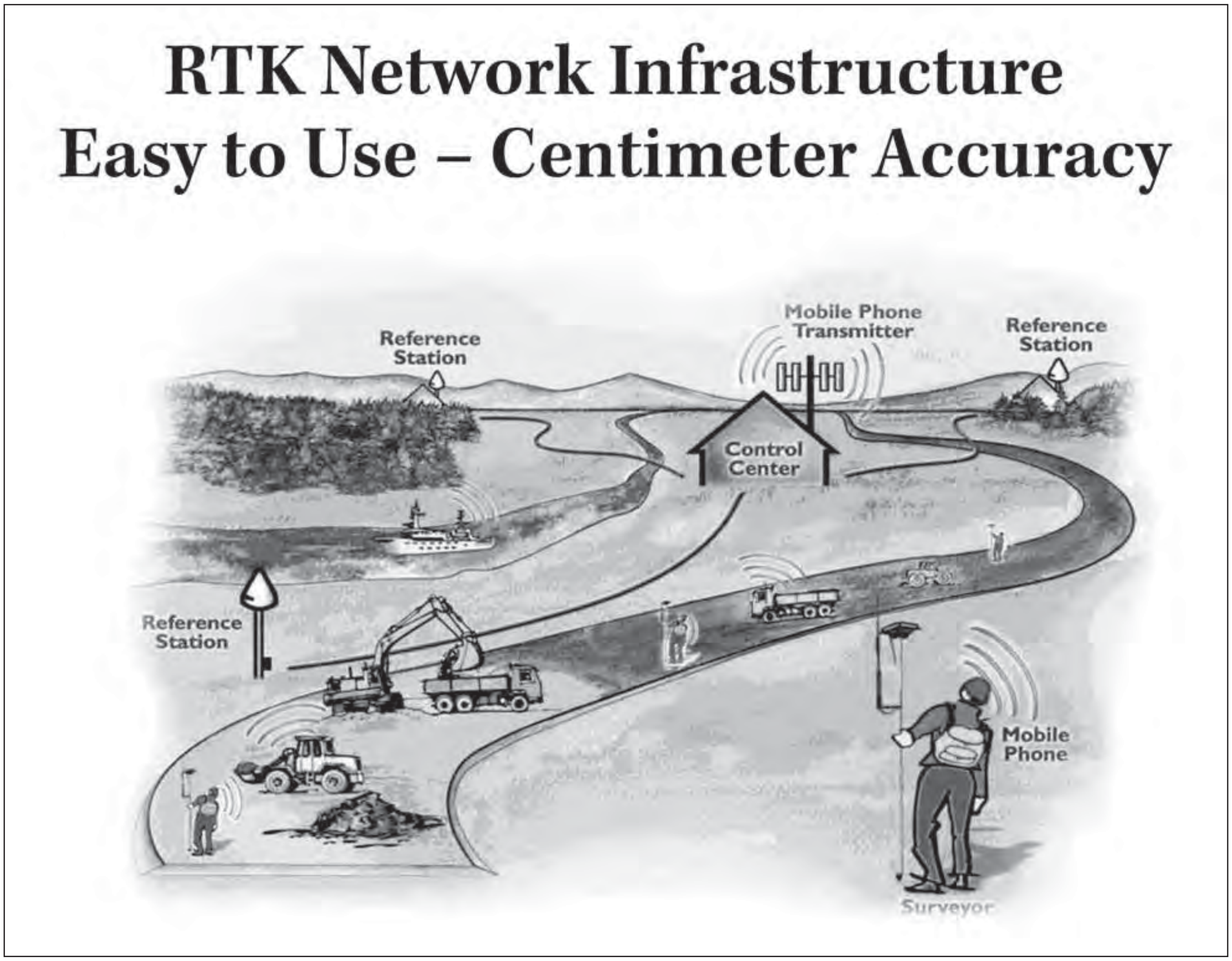


FIGURE 12.5 RTK (VRS) setup. (Graphic courtesy of Trimble © 2008)

mally make no assurances about the resulting accuracy of positions.

Network operators usually provide maps of the network in DXF format that can be loaded and displayed as background maps on the data collector. When working near the outer limits of the VRS network, this DXF can be linked to the current job as an "Active Map." Your current position will be shown as a crosshair on the map, helping you determine whether you are in or out of the box and by how far. (See Figure 12.9.)

VRS PRECISE VERTICAL PROCEDURE

VRS can be used for a variety of surveying tasks including many components of construction surveying; however, the surveyor should (as with all of his or her equipment) pay careful attention to the manufacturer's specifications and his or her experience in using the equipment in choosing which construction tasks are an appropriate use of VRS equipment and technology. The methods described here represent Dewberry's experiences using VRS.

For the best and most consistent vertical results using VRS, a modified version of the NGS 58 GPS leveling procedures should be used. The process is as follows:

- The point must be measured twice, with the second measurement being four hours different (earlier or later) in satellite orbit.
- Vertical dilution of precision (VDOP) must be below 2.5, and below 2.0 is preferred for critical control points.
- Root mean square (RMS) must be below 24, with less than 20 preferred.
- There should be open sky with reference to the satellite configuration at the time of the shot.

For example, the points can be measured in the morning, then once again later in the afternoon on the same day, or they can be measured in the morning one day and then in the afternoon the next day or even in the afternoon any day later in the week. It is the change in configuration of the satellite orbits that occurs over the four-hour period that is critical to the success of this variation on NGS technique.

For those projects in which the supervising professional land surveyor concludes that critical vertical measurements can be acceptable in the ±2-cm (0.06-sft) range, this modified method of VRS location may provide the necessary qual-

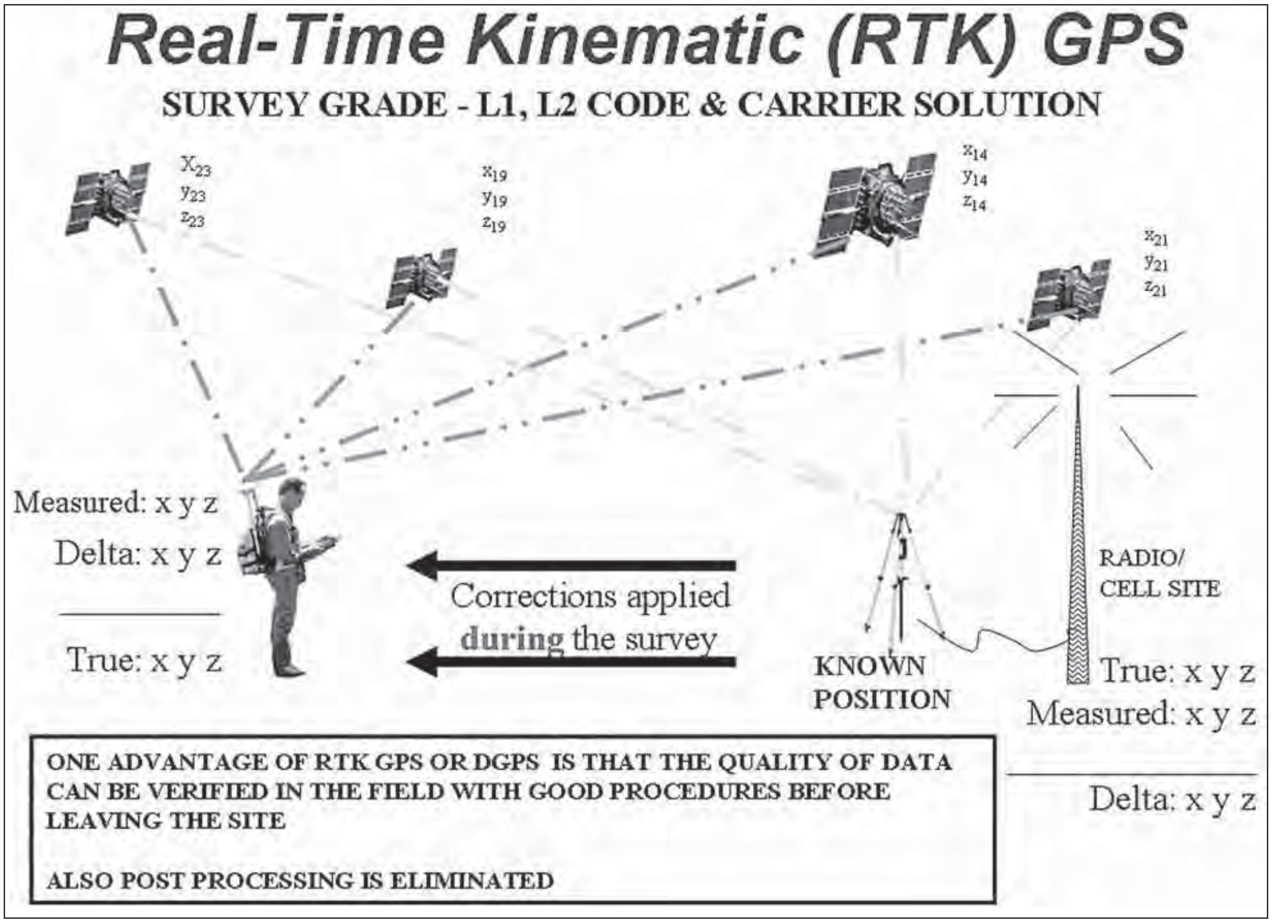


FIGURE 12.6 RTK GPS survey grade code and carrier solution. (Graphic courtesy of Trimble © 2008)

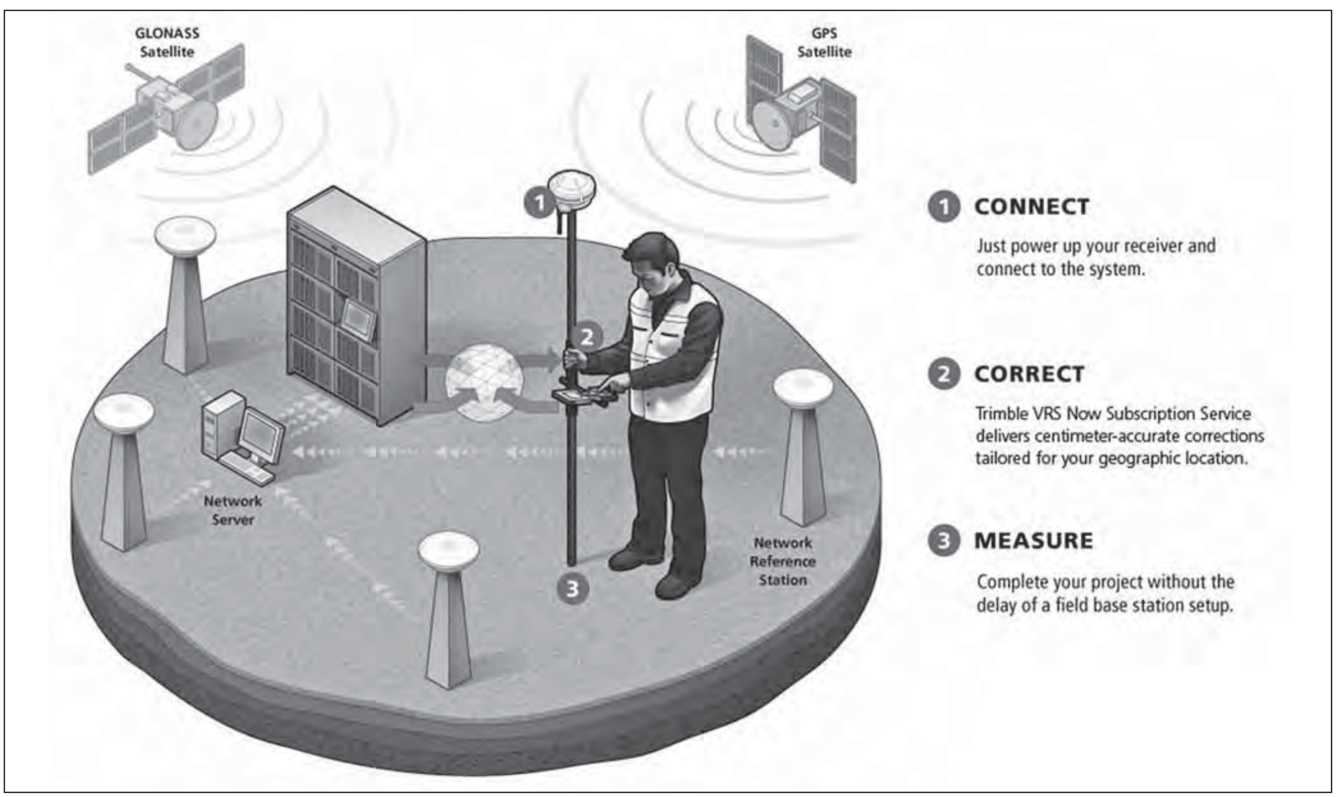


FIGURE 12.7 VRS RTK rover function—connect, correct, measure. (Graphic courtesy of Trimble VRS Now Subscription Service courtesy of Trimble © 2008)

- VRS horizontal coordinates are generally quite reliable (1 to 1.5 cm).
- VRS vertical reliability is much more difficult to attain (typical of all GPS—2 cm or more being normal at this time).
- Five satellites will provide a VRS 3D fix sufficient for horizontal location but with poor vertical reliability. For reliable vertical positioning, seven or more satellites is recommended.
- Running a current vertical dilution of precision (VDOP) plan is required. There are definite VDOP spikes that need to be avoided. VRS positioning sessions tend to be very short in duration and we have found them quite sensitive to VDOP despite the corrections process. Currently we are seeing short periods of VDOP spikes of 6 without GLONASS.
- For critical locations try to keep the VDOP at 2 or less and, naturally, with as much open sky as possible. VDOPs below 3 will often work, but the results are not as reliable.
- Cell connections, VRS initializations, and vertical quality problems often occur around the time period before and after local noon. Unless doing rough topo, crews should avoid measurements during this period. Geometric planning (DOP) doesn't help with predicting this, but checking the solar weather sites can be useful for predicting this. In theory, the VRS system corrects for this, but in practice, we have had enough problems that we take the theory with a grain of salt.
- The quality of the cell data link is important, especially for the vertical. Quite frequently a crew can connect to the data service, the Internet, and the VRS server but experience an erratic correction stream—that is, a data flow characterized by pauses followed by steady flow and then pauses again. The rover software doesn't seem to be able to simply apply the corrections then wait for the next burst and add those properly into a solution. A steady stream during the full measuring session seems to be required.
- The RMS displayed during the measuring session (as well as the H&V estimate of precision) has to be watched closely. RMS can be more difficult to interpret in non-open-sky positions than Trimble lets on. We used to let RMS rise up in to the 30 to 35 range and still take a measurement, but experience has led us to not store critical shots if the RMS is much more than 22 to 24, and under 20 is much better.
- Also, if there is Internet latency affecting the VRS base stations in a particular area, the server software will drop stations unannounced. If this happens during a measurement session, the results can be poor and at odds with what is reported on the screen during the session.
- We have tried a Trimble suggestion of revisiting important stations a second time with 4 hours' separation in satellite orbit configuration on the theory that the true vertical value will lie between the two measurements. The results aren't clear as to this actually being the case, but continue to do it as a check on important points.
- If within a short distance (10 km, 6 mi) of a system base station, shift to multistation style (selects nearest base station) and RTK survey off the single base station. Results using this method can be quite good at even longer distances.

FIGURE 12.8 GNSS real-time network RTK surveying—lessons learned using the VRS system.

ity of vertical positions. Results should be checked with a suitable quality assurance (QA) process such as by running differential levels through a small selection of points distributed across the project.

What the Survey Controller Precision Estimates Mean

When using RTK, you are looking at a distance-distance intersection, satellites to receiver.

- The horizontal and vertical precision estimates show how far the worst distance measured lies from the center of the solution.
- When that distance is less than L1/4, the initialization is probably good. The L1 wavelength is 19 cm, so L1/4 is 4.75 cm or ~0.15′.
- When it's over L1/2, it's probably bad. L1/2 is 9.5 cm or ~0.30′.
- The hypotenuse of the horizontal and vertical precision estimates is how far the worst distance comes from meeting where the others intersect. This hypotenuse should clearly be less than 0.0475 m or larger than 0.0950 m.

Note: The estimates that are reported on the controller are not how good the actual X, Y, Z position is that you have collected but how well the GPS measurements are agreeing. Therefore critical measurements must be collected with multiple occupations to ensure consistent results.

GUIDELINES: WHEN TO USE VRS RTK AND RADIO RTK—LESSONS LEARNED AND BEST PRACTICE

The appropriate uses for VRS GNSS RTN surveys are the subject of much discussion. Also, on large projects that are joint ventures or where there are loans of crews between offices, it is necessary to note what types of tasks a party chief can expect to be asked to do with VRS or radio RTK when working out of their usual office.

DOT Work

Authorization for the use of VRS in department of transportation (DOT) surveys is very limited or not authorized at all. It is very important to clarify this with your DOT before using VRS on any DOT project. In contrast, radio RTK has sufficient elevation performance to now be acceptable for many portions of topographic surveys, such as edge of paving, in many states.

1. Planning:
   a. Be aware of satellite geometry, as it will affect accuracy. This is particularly true of the vertical component of the position.
   b. For best results, avoid positioning sessions in which the VDOP (vertical dilution of precision) is greater than 3, and preferably keep VDOT below 2.5. This is particularly true when observing control stations.

2. Observing control:
   a. A minimum of two 10-second measurements are required with a RMS* < 24.
      (*This refers to the RMS value shown on the data collector screen while in a VRS session, which concerns the quality of the satellite wavelength solution. It does not refer to the RMS associated with position quality found elsewhere in position reports, etc.)
   b. For best accuracy, the two measurements need to be made with different satellite geometries.
      i. A 4-hour difference in satellite geometry will yield the best results.
      ii. The difference between the two measurements is double the probable error. If it exceeds project requirements, reobserve again after a 4-hour change in satellite geometry.
      iii. Repeat this method until accuracy meets project requirements.
   c. If repeat measurements are made one after the other in the same time period, you must reinitialize the receiver between measurements.

3. Observing topo:
   a. One 5-second measurement (the Trimble default) with an RMS < 24. A 5-second measurement session provides three positions.
   b. If initialization is lost due to high RMS, all measurements within that initialization should be checked.

4. Site calibration:
   a. A site calibration adjusts the measurements to local control.
   b. Errors in the control or the VRS measurements will change the observed values. In most cases the values will be less accurate after a site calibration.

FIGURE 12.9 VRS RTK positioning procedures.

Curb and Gutter and Other Concrete Structures

Many surveyors using VRS find it suitable for the horizontal alignment layout of curb and gutter for *private-sector* construction. VRS is not considered suitable for the vertical portion of any concrete work. Offices that currently use VRS for alignment always use either trigonometric leveling or differential leveling to determine the elevations of the VRS points for cutsheet computation. For smaller sites, some surveyors consider construction layout with a conventional total station as being as fast as or faster than VRS because this method produces adequate horizontal and vertical accuracies at the same time.

Experienced GPS users considered radio RTK (with proper procedures and quality assurance/quality control) suitable for layout of curb and gutter alignments for both horizontal and vertical on private-sector projects.

ALTA Boundary and Control Recovery

In those applications not requiring a tight vertical component, VRS has been found to be a very efficient method of survey and often a huge time-saver over conventional methods. So long as multipath situations are guarded against, VRS produces satisfactory horizontal locations.

Aerial Mapping Control

Horizontal. For practically all scales of mapping, except possibly very low level VDOT helicopter-based highway mapping, the horizontal positions obtained with VRS using proper methods are sufficient for control. VRS allows very large areas to be controlled quickly. Where radio reception permits, radio RTK will yield accuracy results as good as or better than VRS.

Vertical. For mapping scales in the range of 1:80, 1:100, 1:200, and so on, and/or for 1-foot contour mapping or greater, VRS aerial panel point elevations taken four hours apart in satellite orbit time and following good VRS procedures should provide adequate vertical control. Survey control produced using VRS for mapping scales in the 1:10 to 1:50 range may not be adequate and would require clarification with the photogrammetrist before being used.

Where radio reception permits, radio RTK with proper QA/QC will support all levels of aerial mapping control horizontally and vertically, with the possible exception of helicopter-level mapping (500-foot flying height).

Initial Base Station Positioning for Radio RTK

When a radio RTK base station is to be established for calibration to an existing site, it is better to use VRS to establish the base station WGS84 coordinate, rather than relying on the base station to produce an uncorrected, autonomous position. This procedure results in a better fit between the radio RTK survey and any VRS survey work, if both are used on the site.

Setting Control Station Pairs for Large-Site Mapping

When surveying or mapping large sites and where intervisibility between control stations is not easily set up, VRS is a convenient and accurate tool for setting control station pairs for conventional mapping and boundary location. This procedure has resulted in great time savings on jobs where it has been used.

For smaller sites with acceptable radio reception, radio RTK can be used in a similar manner but with greater precision expected in the vertical.

As-Built Surveys

Many as-built surveys do not require rigorous vertical information, so VRS is very useful for these surveys.

VERTICAL ACCURACY DIFFERENCES BETWEEN VRS AND RTK

The typical manufacturer's advertised vertical specification for the antenna for both VRS and radio RTK operations is ±2 cm (0.06 sft).

Radio RTK under ideal conditions often produces verticals in the ±1-cm (.03-sft) range, and the verticals are more consistent between each other than is seen with VRS.

VRS RTK measurements in the current network under ideal site conditions are often in the ±2-cm range, but ±4 cm (0.12 sft) is not uncommon.

This performance difference when using the same equipment for both styles of survey is due to the following factors:

- Corrections for the rover in radio RTK derive from a single base station a short distance away—one local opinion.
- Corrections for the rover in VRS RTK are an average of the corrections from six base stations at long distances from the rover—multiple nonlocal opinions.

Project Size and Radio Reception Considerations When Selecting VRS or Radio RTK for Projects

VRS works reliably over entire regions but is subject to local cell phone interference from high-rise buildings in urban areas and tree coverage in rural and urban areas.

Radio RTK is restricted by the range of the radio transmitting the base station correction. In wide-open terrain, the base station with radio repeater can work at ranges up to 4.5 miles. By itself, an internal base radio has a range of 1 to 1.5 miles. However, in densely wooded areas, low areas between hills and high-rise urban areas, radio range, even with the repeater operating, can be less than a quarter mile. Also, the GNSS radios are configured to cease transmitting whenever there is voice traffic on their channel.

The accuracy of RTN systems continues to improve, and a natural question is how accurate could these networks get over time?

As an example of how well one of these networks can perform, the following information comes out of the South Carolina State Geodetic Survey, which is establishing a high-precision statewide VRS network. Cost does not appear to be an issue in the construction of this network, since it includes first-order vertical information on many of its base stations (running first-order levels is *very* expensive).

Currently, 30 of the 45 planned Trimble R5 base stations (GPS and GLONASS) have been built, and the VRS network is running Trimble RTKNet software. Two types of tests have been run for comparison against each other. The tests have been run with and without GLONASS. GLONASS has been found to make a difference.

Test Type 1 of the SC VRS network yielded 1.9-cm 2D (horizontal) rmse 95 percent and 2.25-cm 1D (vertical) rmse 95 percent when compared to 50 NGS height modernization points spread over an 11-county area.

Test Type 2 used 24 first-order vertical benchmarks recently established with classical first-order leveling, which resulted in a 1.2-cm standard deviation in the horizontal and a standard deviation of 1.3 cm in the vertical.

REVIEW OF U.S. SURVEYING STANDARDS AND SPECIFICATIONS

Specifications

In order to adequately evaluate and judge the quality of survey work, a set of standards must be developed. Standards are statements of required accuracies of survey measurements, such as traverse for horizontal measurements or level loop closures for vertical measurements. Specifications detail the necessary steps (procedures) to achieve the required standard, such as the number of angle repetitions or the quality of the instrument. The National Geodetic Survey (NGS), formerly known as the U.S. Coast and Geodetic Survey (USC&GS), implemented the most widely accepted set of standards of accuracy and specifications to support these survey classifications. The NGS is a division of the National Oceanic and Atmospheric Administration (NOAA), which is part of the U.S. Department of Commerce.

Issued by the Federal Geodetic Control Subcommittee (FGCS), the *Standards and Specifications for Geodetic Control Networks* (September 1984, reprinted October 1990) includes the familiar third-order, class I and II classification, now the basis for many older civilian survey specifications. This document uses the older form of accuracy expression called *proportional ratios* (1:10,000, etc.) to classify the different orders of conventional surveys. (The ratio 1:10,000 means that for every 10,000 units of horizontal measurement, the tolerance or error will be no greater than 1 unit.)

As the name implies, this document was created primarily to support the development of geodetic control networks. However, previous editions of these standards and specifications state that the third-order requirements were designed for use on local mapping and engineering projects. To the land development surveyor, the specifications required for angular, linear, and vertical closure are of great importance. The global positioning system (GPS) and the widespread availability of least squares adjustment software have caused NGS and other agencies, such as state highway departments, to now classify surveys by positional tolerance.

Horizontal Third-Order Specifications. These specifications state that the maximum angular closure for third-order class I shall be $10''\sqrt{N}$ and class II shall be $12''\sqrt{N}$, where N equals the number of legs in a traverse. Further, minimum position closures for third order are to be no less than 1:10,000 for class I and no less than 1:5,000 for class II.

Vertical Third-Order Specification. For level loop closures, the publication states that the third-order accuracy requirement is 12 mm $\sqrt{E}$, where E equals the length of the level loop in kilometers. The vertical closure requirement can also be stated as 0.05 feet $\sqrt{M}$, where M equals the length of the level loop in miles.

Readers are encouraged to obtain copies of the previous editions of this text as well as *Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys* (February 1974, reprinted January 1976) and *Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys* (July 1975, reprinted May 1978) for supplemental information. These versions provide valuable procedural guidelines and specification details pertaining to the establishment of horizontal and vertical control in prior decades.

For land development projects, unless the state board of registration has developed more rigorous minimum standards, the commonly implied standard is third order. Work performed for state or local government agencies is usually subject to specifications similar to third order. The exception to this rule of thumb is that for most land development projects, the objective is to make the civil improvements to the site operate properly. In other words, the objective is for the storm drain system to carry the runoff to the desired place, the sanitary sewer system to do likewise, and the curb and gutter for streets and parking lots to drain properly. In this sense, most land development surveying is performed to construction order. It is important to remember that it is wasteful to perform fieldwork in support of land development to a higher order of accuracy than required.

First- and Second-Order Horizontal Specifications. For more accurate work, the USC&GS developed the first-order and second-order standards and specifications. The triangulation network that covered the United States prior to GPS was composed primarily of first- and, to a lesser extent, second-order stations. The horizontal component of these orders is now commonly considered a part of GPS operations due to the expense of carrying out these surveys with conventional instruments.

National Datum Adjustment Lineage—Critical Knowledge for Today's Land Surveyor

To follow in the footsteps of prior surveyors' control work, it is necessary to understand the history of the national geodetic datums. The national geodetic network has evolved very rapidly over the last 20 years and many new surveys often have to reconcile multiple prior official coordinate systems before design and construction work can proceed.

Horizontal Network. The most current version of the national horizontal datum at this time is the NAD 83 (NSRS2007). This represents the first version of the new adjustment standard, the National Spatial Reference System of 2007, which includes only those control stations with GPS observations. (See Appendix A for additional information on State Plane Coordinate Systems and map projections).

Just as many ground monuments of the NAD 27 network with low-order survey observations were not included in the NAD 83 readjustment, NAD 83 ground points without GPS observations were not brought forward into the NAD 83 (NSRS 2007) network. This progressive loss of modern coordinates on existing ground monuments can have a significant impact on the land development surveyor tasked with bringing an old project into active status. Significant additional surveying may be required to verify and bring forward old control.

Vertical Control. A federal network exists for vertical control. Prior to GPS, the vertical system was known as the National Geodetic Vertical Datum of 1929 (NGVD 29). It too has been readjusted and is now known as the North American Vertical Datum of 1988 (NAVD 88). (See Appendix A for additional information on State Plane Coordinate Systems and map projections.)

GPS measures heights above a global mathematical surface model called an *ellipsoid.* In the United States, the ellipsoid of choice at this time is the World Geodetic System 1984 (WGS 84). The current version of the global geoid used in the United States is GEOID03. For GPS operations, an elevation or orthometric height is now composed of three parts: the height of the measured point above the reference ellipsoid, the height of the antennae above the measured point, and the separation distance of the geoid from the ellipsoid.

Global Positioning System (GPS)

The FGCS has developed the *Geometric Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques.* It created new survey categories, including AA, A, and B order. The corresponding relative position accuracies for the new orders are 1:100,000,000, 1:10,000,000, and 1:1,000,000. The traditional first, second, and third orders are now included in the C group in the FGCS document (as C1, C2-I and C2-II, and C3), with the corresponding accuracies being 1:100,000, 1:50,000 (or 1:20,000), and 1:10,000. (See Appendix A for additional information on State Plane Coordinate Systems and map projections.)

The surveyor should consider these requirements in the design, execution, and adjustment of GNSS work to support land development. Land development surveyors will most likely encounter this standard and specification if they are involved in the establishment of geodetic control for the creation of a Geographic Information System (GIS). Most local jurisdictions have created specifications for the accuracy of ties to this type of control, and almost all land development projects will make use of GIS horizontal and vertical control, particularly in metropolitan areas.

In November 1997, NGS issued NOAA Technical Memorandum NOS NGS-58, *Guidelines for Establishing GPS Derived Ellipsoidal Heights* (*Standards: 2cm and 5cm*), Version 4.3. Authored by David B. Zilkoski, Joseph D. D'Onofrio, and Stephen J. Frakes, the guidelines established procedures for using GNSS to obtain ellipsoidal heights at the 2-sigma (95 percent confidence) level. Not to be confused with orthometric heights, which are what is used in land development, the guidelines are based on extensive research by NGS and require specific observation techniques. Land development surveyors seldom run this type of control but do use modifications of the specifications when determining orthometric heights (elevations) using the new GNSS real-time kinematic (RTK) surveys based on real-time networks (RTN).

To obtain control-quality 2-cm accuracies using GNSS RTK RTN, users are required to use dual-frequency receivers and fixed-height tripods, make observations of a certain length in time (5 seconds to 1 minute), take multiple sets of observations at different times during the day (twice, on two different days, is optimum, to benefit from changes in satellite geometry), setting the elevation mask on the receiver to 13°, and ensuring that VDOP values for the satellite constellation are at 2 or below before occupation of the stations. The use of GPS has caused a rethinking of control network concepts. NGS has discovered that with the addition of the Continuously Operating Reference Stations (CORS) into the National Spatial Reference System (NSRS), long-range horizontal accuracies in the 1- to 2-cm range and vertical accuracies in the 2- to 4-cm range are possible.

In 1998, the Federal Geodetic Control Subcommittee (FGCS) and the Federal Geographic Data Committee (FGDC) issued the Geospatial Positioning Accuracy Standards. More information can be found at www.fgdc.gov/standards/status/textstatus.html. (See Appendix A for additional information on State Plane Coordinate Systems and map projections.)

Another change involves a move away from determining accuracy based on distance. NGS found that GPS accuracy does not degrade rapidly with distance. This means the accuracy between unconnected points between which a direct measurement had not been made is not affected as dramatically with GPS as with traditional, ground-based surveying methods.

However, it is still good surveying practice to directly connect points that are very close to one another. Another new concept is that of *local* accuracy and *network* (sometimes referred to as "absolute") accuracy. NGS defines the local accuracy of a control point as a number, expressed in centimeters, that represents the uncertainty at the 95 percent confidence level in the coordinates of the point relative to the coordinates of other directly connected, adjacent control points. The reported local accuracy will be an approximate average between the point and other adjacent points. Network accuracy is defined in the same terms, but with respect to the geodetic datum, in this case the CORS stations, it is assumed to have no (or practically no) positioning error. NGS is in the process of converting all accuracy statements using this new concept. GPS real-time networks provide NSRS 2007 network accuracy due to their network of base stations being anchored on one or more high-order NGS CORS stations.

Using first-order points as an example, network accuracy in NAD 27 was approximately 10 m, while local accuracy was 1 part in 100,000. With NAD 83, network accuracy was reduced to 1 m, while local accuracy remained the same. But with the addition of GPS into the High Accuracy Reference Networks (HARN), the network accuracy improved to a tenth of a meter, and local accuracy for B-order marks improved to 1 part in a million, while A-order marks improved to 1 in 10 million. Finally, with CORS, *both* network and local accuracies have improved to 1 cm. Both standards are relative accuracy measures.

Ellipsoidal/orthometric heights are also included in the new standards. The difference between horizontal control, discussed previously, and vertical control is that horizontal accuracy is expressed as 2D (x, y) circular error, vertical control accuracy is expressed as 1D (z) linear error, and both are expressed at a 95 percent confidence level. Additionally, these standards meet the needs of GIS users.

ACSM/ASPRS ALTA Standard—Classification and Specifications for Cadastral Surveys

For commercial property, another standard exists. Many times a lender is called on to make a loan on property that is across the country. Furthermore, because there is such wide variation in the standard of surveying between different locales, clients need assurance about the degree of accuracy of the survey work. Members of the American Land Title Association (ALTA), in cooperation with the American Congress on Surveying and Mapping (ACSM), realized that no national standard existed to judge the accuracy of land title surveys. So, in 1962, the ALTA/ACSM *Minimum Standard Detail Requirements for Land Title Surveys* were developed. Some state boards of registration have incorporated the ALTA/ACSM Standards into the accuracy requirements of their minimum standards, and land development surveyors should check their local and state requirements to see whether this condition exists and applies to their projects.

The ALTA/ACSM standard has undergone a number of updates, starting in 1986, and most recently in 1999 (2005 version). The original rationale behind these standards was that the title insurance industry needed to be held responsible for the legal aspects of accuracy standards, while the surveying community would be responsible for the surveying and accuracy aspects. The title industry has generally not concerned itself with the accuracy portion of the standards but instead has relied on ACSM to develop them. With the 1992 changes, ALTA and ACSM separated the survey accu-

```
Positional Tolerance Check (FeetUS)
Allowable Tolerance = 0.0700 + 0 PPM
Tolerance Check Confidence Region = 95%

Stations              Horizontal       Semi-Major-Axis          Ratio
From      To           Distance       Actual      Allowed   Actual/Allowed
100       102          622.5713       0.0548       0.0700       0.7835
101       103          837.0443       0.0596       0.0700       0.8507

Connections Checked    = 2
Number of Failures     = 0
```

FIGURE 12.10 Least squares adjustment—positional tolerance check.

racy specifications from the rest of the standards to allow for the adoption of necessary updates without having to revise and readopt the entire document. That portion of the standard is now called the *Accuracy Standards for ALTA/ACSM Land Title Surveys* and is included in the Appendix G of this text.

In the most recent version of the ALTA/ACSM Standards, the organizations have reverted to a positional accuracy standard. This new standard allows surveyors to employ appropriate procedures and equipment as long as a maximum allowable amount of positional uncertainty in any corner location is not exceeded. Surveyors should perform a least squares adjustment of the survey observations to ensure compliance with the standard.

This portion of the output from Figure 12.10, STARNET[1] Least Squares Adjustment, illustrates the outcome of the least squares procedure that provides compliance with ALTA requirements.

National Map Accuracy Standards

A third standard that land development surveyors are likely to encounter is the national mapping standards. See Appendix A for extensive information on this topic and additional information on State Plane Coordinate Systems and map projections.

The use of GPS has become more prevalent for the establishment of the horizontal and vertical control for aerial mapping projects. With recent advances and by following certain guidelines, NGS feels that current vertical accuracies for GPS, under ideal conditions, are on the order of 2 to 5 cm.

Equipment Specifications

Conventional angle- and distance-measuring devices are now evaluated on the basis of their accuracy and precision. Specifications created by equipment manufacturers commonly list the accuracy, as in the case of an angle-turning instrument being reported as $\pm x$ number of seconds. For electronic distance-measuring devices (EDMs), the accuracy is defined as being $\pm x$ number of millimeters plus x parts per million (PPM). For example, a 1-km measurement made with the most commonly used EDM (± 5 mm $\pm$ 5 PPM) will contain a plus-or-minus uncertainty of 10 mm. Likewise, the accuracy of levels is listed as being able to achieve a closure of x times the length of a level run.

These plus-or-minus amounts are supplied by the manufacturers and are the result of rigorous statistical testing involving thousands of measurements. For land development work, most surveyors can use theodolites having an accuracy specification of ± 5 or 6 seconds and EDMs having an accuracy specification of ± 5 mm plus 5 PPM. More accurate instruments specified as "one second" are increasingly common in everyday land development surveying.

Digital self-leveling levels with automated data reduction and adjustment software that are capable of achieving a closure of ± 0.01 ft in 1 mile of double run levels are commonly used by today's surveyors.

It is a widely held misconception that the manufacturer's accuracy specification for a theodolite refers to the plus-or-minus uncertainty in *each angle*. This is not true. The de facto specification for instrument accuracy is referenced to DIN 18723 (DIN spec) developed in Germany by the Deutsches Institut für Normung. This method of evaluation refers to the plus-or-minus uncertainty in each *direction* or *pointing*, a direction being composed of a direct and reverse pointing to a single target. An angle is considered to be the difference between two directions or pointings.

REVIEW OF SURVEYING STATISTICS

Accuracy and Precision

To be able to discuss the true significance and meaning of specifications like third order and the ALTA/ACSM standards, we must first define some relevant terminology, such as *accuracy* and *precision*. *Accuracy* is defined as "being close to the truth." In other words, for something to be accurate or to possess accuracy, the user or recipient of the work needs assurance that the product is true or correct.

Another frequently used term in discussing specifications is *precision*, defined in a surveying sense as "being able to repeat a measurement over and over again and being able to obtain close to the same answer for each one." The classic example is that of a rifleman and a bull's-eye target. With reference to Figure 12.11, if the rifleman is able to cluster his shots together at the edge of the target, the results are said to be precise but not accurate. In other words, he was able to

[1]The software referred to is Star*Net, Starplus Software, Oakland, California.

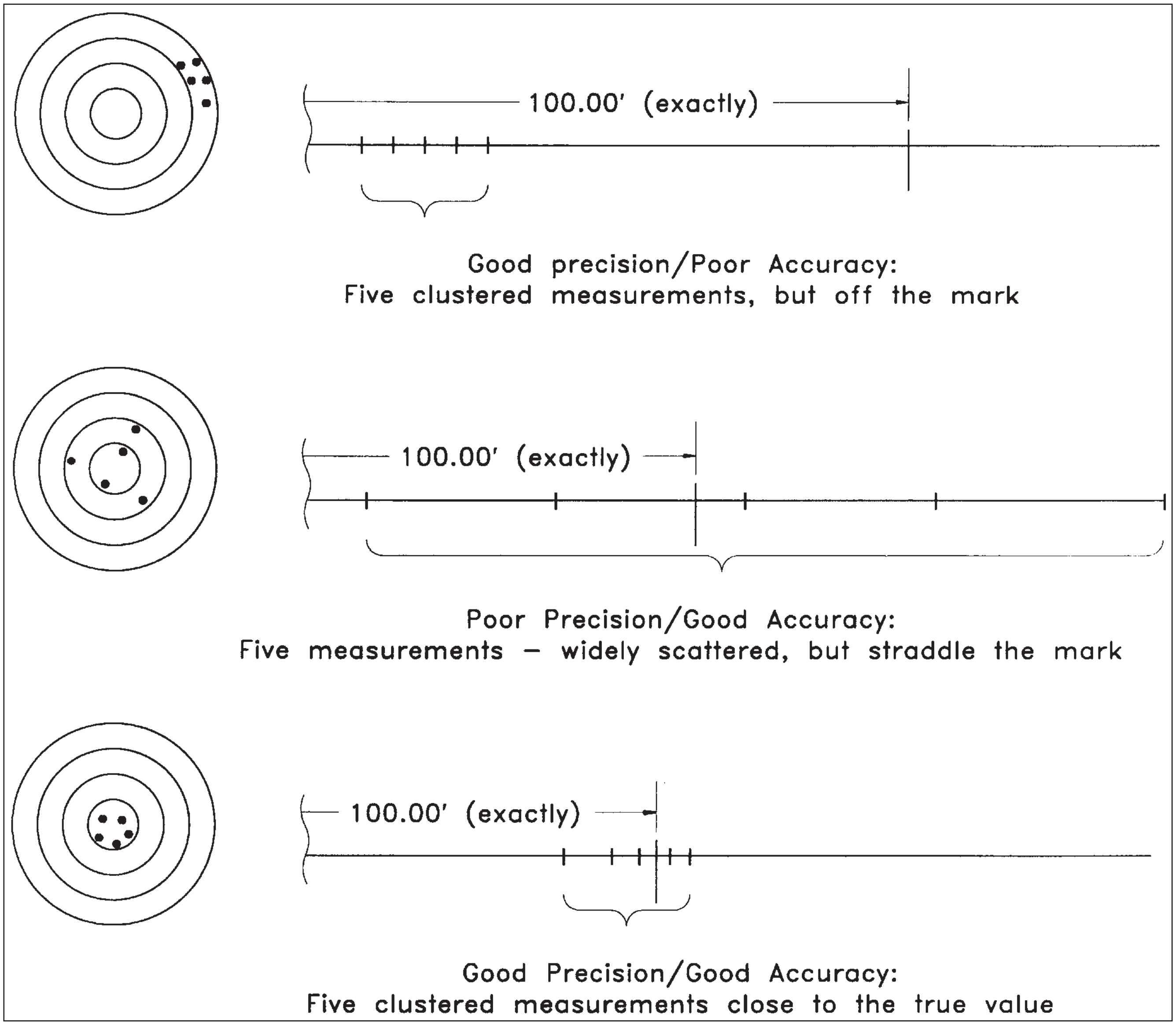


FIGURE 12.11 Accuracy and precision for a bull's eye and the relationship to measurements.

shoot close to the same mark but not near the center of the target. On the other hand, if his shots were spread out all over the target, the results would be neither accurate nor precise. An exception would exist if the mean of the shots were in the center of the target, in which case his shots would be considered to be accurate but not precise. If, however, his shots were clustered around the center of the target, the results would be said to be both accurate and precise.

Relating this to survey measurements, if a theodolite or EDM is accurate it allows the operator to turn better angles or measure better distances such that the measured quantity is (hopefully) close to the true site conditions. If the operator has a good eye, turns the angles carefully, and controls any systematic errors, that operator is described as having the capability of producing accurate angles.

So-called reading and pointing errors can contribute a great deal of inaccuracy. Any errors caused by the estimation needed to read an angle on an optical theodolite can often contribute more inaccuracy than pointing errors. The precision of an instrument is classified not only by its ability to accurately turn angles but by its ability to turn accurate angles repeatedly.

Land development surveyors will encounter survey standards and specifications in two forms. The most familiar is the standard that dictates horizontal and vertical closures of a traverse or a level run, while the less familiar is the process of establishing the accuracy of a piece of equipment (see "Types and Sources of Error" for more detail). The discussion of precision and accuracy plays a part in our further discussion of standards and specifications and adjustments.

Types and Sources of Error

As mentioned previously, all measurements contain errors. The first type of error is the *blunder* or *mistake*. An example of a blunder would be recording an angle as 29° instead of the instrument reading of 92°. For purposes of our discussion, it is assumed that the surveyor has eliminated the outright mistakes or blunders in the work. The other errors that will be dealt with in this chapter fall into two categories: *systematic* (both equipment and natural) and *random* or *accidental*.

Systematic Errors. Systematic errors are considered either *constant* or *variable*. Constant systematic errors can, to a certain extent, be corrected. Examples of constant systematic equipment errors are steel tapes that measure too short or too long or instruments and EDMs that are not properly calibrated. These errors generally have the same magnitude and the same algebraic sign. Using a steel tape that is too short will consistently provide distance measurements that are too long. An EDM that is not accurately calibrated will consistently measure distances incorrectly, that is, short or long. Temperature corrections for measured distances (taped and EDM) would be applied to eliminate systematic errors. Other sources of constant systematic error include prism offsets, adjustment of prism pole, and optical plummet adjustment. Equipment errors can normally be corrected by accurate calibration or by following the proper methods and procedures.

Variable systematic errors can be alleviated by following proper methods and procedures. Examples of variable systematic errors are differential heating of a tripod by sunlight, movement of a tripod or instrument due to wind or vibration, and tripod settling over the course of a set of observations. An example of such a procedure is performing observations over a short period of time to eliminate the possibility of differential tripod heating.

Natural Errors. Natural errors include such things as temperature, barometric pressure, humidity, and refraction. Surveyors are familiar with the correction for the first two because the PPM setting on an EDM is dependent on temperature and barometric pressure. Of the variable errors, refraction is probably the single greatest source of angular error. It is affected by humidity, and it is hard to detect and even harder to predict. However, it can be avoided or reduced by making observations over a longer period of time and by being conscious of how it can affect angular measurements.

In periods of low or no wind, care must be exercised due to the creation of air bubbles, or air strata of differing density. Air strata are generally of greater density near the ground and lie roughly parallel with it. Over sloping terrain these strata of different densities are not horizontal, and a ray of light passing through them will be bent horizontally as well as vertically. A line of sight passing near a building or a tree may suffer a change in horizontal direction. Likewise, a line of sight passing close to the ground may suffer a change in vertical direction. The nearer the cause of the disturbance is to the observer, the greater the angular distortion that is to be expected in the observations. A line of sight that passes over cool areas and then hot areas will bend. Similarly, a line that passes over a body of water is likely to incur horizontal refraction. Refraction will cause a light ray to bend away from low density and toward high density, away from lower pressure and toward higher pressure, and away from lower temperature and toward higher temperature. Making observations at night can alleviate refraction caused by heat waves (shimmer).

Random Errors. Most random errors are caused by a surveyor's inability to aim an instrument correctly, read angles, or measure distances accurately. Unlike systematic errors, which can be corrected or alleviated, random errors have magnitudes and signs that are unpredictable. The theory of probability states that random errors tend both to be small and to distribute themselves equally on both sides of the true value. That is, random errors will manifest themselves as observations that are greater (plus) and lesser (minus) than the true value. It can be shown that, given a sufficient number of observations, random errors will follow predictable mathematical rules. These errors can be plotted on a graph and will normally fall within the familiar bell-shaped curve, known as a *probability curve*. If the observations are plotted on a bar graph, known as a *histogram*, the resulting bars from the graph will approximate the probability curve (see Figure 12.12). Properties of this curve, also known as the *normal distribution curve*, can be described by mathematical parameters.

Probability Theory

The average, or *most probable value*, of these readings is obtained by simply adding them up and dividing by the number of readings. This is known as the *arithmetic mean*. After systematic errors and blunders are removed, the arithmetic mean is accepted as being the most probable (or true) value. If the readings represent a valid sample, the observations will fall on both sides of the mean. That is, some will be greater than the mean and some will be less.

The variances—that is, the mathematical difference between the measured value and the mean—are known as

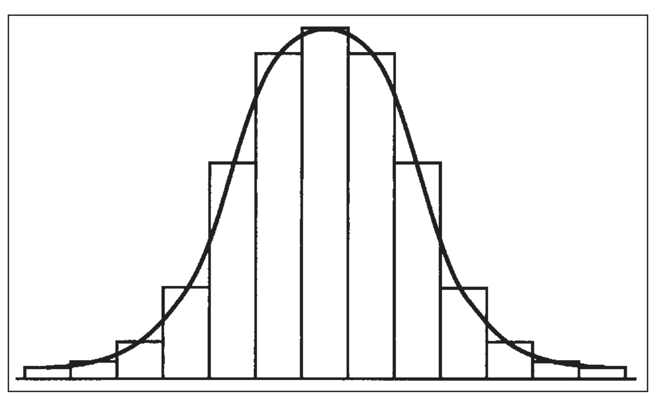


FIGURE 12.12 Histogram.

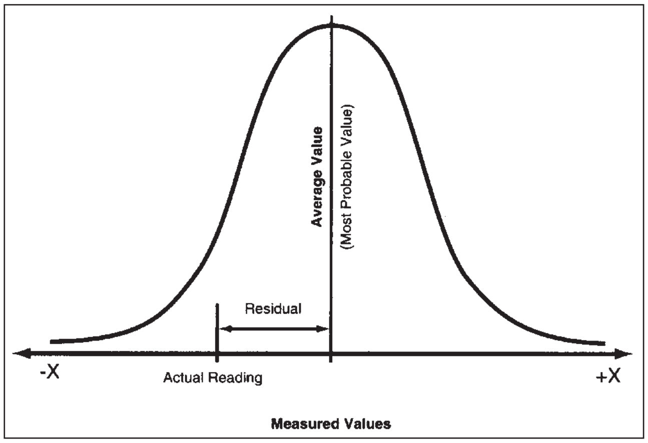


FIGURE 12.13 The residual is the difference between the most probable value and the actual reading.

the *residuals* (see Figure 12.13). The term used to define the plus-or-minus uncertainty in a measurement is *standard deviation,* or *standard error.* This term is used to express the accuracy of a group of measurements or the accuracy of a piece of equipment. It is used for two reasons: (1) to analyze measurements to see if they meet the specification requirements and (2) to establish procedures and specifications to ensure that the work will meet the anticipated standard.

The equation for the standard error is:

$$\sigma = \pm\sqrt{\frac{\Sigma v^2}{n-1}} \tag{12.1}$$

where σ equals standard error, Σv^2 equals the sum of the residuals squared, and $n - 1$ equals the number of observations minus one. It can be said, statistically, that any one observation has a 68.3 percent chance of falling within the range of the mean $\pm\sigma$.

The least squares adjustment to be discussed under "Least Squares" effectively treats all the measurements as a large sample and simultaneously applies the corrections for a best fit. Figure 12.14 illustrates the different levels of probability. Even though the standard error derived by these formulas is expressed as being 68.3 percent, surveys generally require a higher degree of probability. Most surveys require a certainty or confidence level of 95 percent, or 2σ, also known as "2 sigma." Depending on the circumstances, some surveys will require a 99 percent certainty (2.5σ) or even 99.7 percent, which is 3σ, known as "3 sigma" (see Figure 12.14).

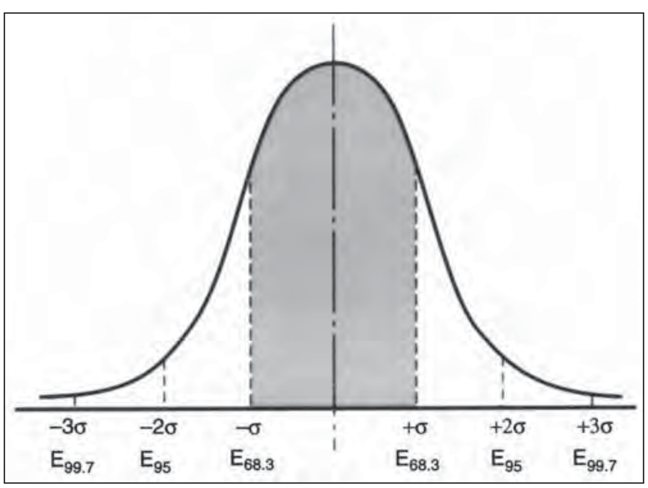


FIGURE 12.14 Levels of probability.

The DIN Spec for Conventional Survey Instruments

Based on the knowledge of these specifications, instruments can be chosen that will meet the requirements. The specifications take into account the accuracy and precision of a given instrument and specify the number of repetitions for each angle. Error budgets can be established that give the surveyor an idea, based on statistical knowledge, of the type of instrument necessary to meet a certain specification and the procedures that must be followed to achieve the desired result. As mentioned earlier, the DIN spec relies on specific procedures, including the number of targets to be sighted and advancing the circle between sets, and so on, to establish the accuracy of a given instrument. The result of these procedures is the standard error of the mean of a pair of face I (direct) and face II (reverse) readings to a single target. If the surveyor wishes to work with angles as opposed to directions, the manufacturer's stated standard error should be multiplied by $\sqrt{2}$. This is the recommended NGS procedure and is stipulated because angles are the uncorrelated result of the subtraction of directions.

LEGAL DEFENSIBILITY OF SURVEY CONTROL AND GNSS RTN POSITIONS IN LAND DEVELOPMENT SURVEYING

Traditionally, our geodetic control services (NGS) develop and realize the national geodetic datum onto physical control monuments for use by surveyors. Starting from these monuments, and by using accepted conventional and static baseline GPS survey methodologies and data recordation processes, a surveyor can produce a well-understood and explainable (to a jury) fabric of measurements and quality assurance outcomes that support the surveyor's opinion of location in court.

Surveyors in the United States are experienced users of the many National Geodetic Survey control products. As a general rule, we take the quality and authority of the control station positions provided by NGS for granted as gospel. The penultimate role of the NGS from an end user's perspective until the very recent advent of CORS-derived GPS real-time networks has been the realization of the national geodetic datum (coordinate reference framework) onto physical control monuments. With the advent of CORS, the realization of the datum has been shifted from ground monuments to the CORS stations.

This new form of CORS-based geodetic datum realization is a dynamic, continuously evolving reference framework supporting digital communication access. Now, CORS-dependent GNSS RTN provides realization of the national geodetic datum in real time to the remote user at a location of their choosing by Internet-based digital communication methods. This high-precision real-time geospatial coordinate infrastructure is accessible to a wide audience of land surveyors and many other professionals, as well as laypersons, and it will quickly become interwoven with practically every aspect of the daily operation of our society.

There is a problem with this infrastructure, though. Despite the high level of trust placed in the NGS by the land-surveying community, their coordinate positions are *not legal positions;* that is, they do not necessarily have legal standing in a local court of law because they do not fall under one of the national- or state-certified weights and measures acts. What this means for the land surveyor is that the coordinates derived from NGS CORS through GNSS RTN networks may not be acceptable as evidence of location simply on their own merits.

For instance, we assume that our steel surveying tapes (chains) are certified by the manufacturer to comply with the National Institute of Standards and Technology (NIST) standard for Metal Tapes: Surveying, Oil Gaging, and General Purpose; Metal Scales (10030C). In a court of law, we can use this information to support measurements we have made using steel tapes constructed in accordance with this standard. In a more mundane and frequent experience of certification of a measuring device, every time we fill our vehicle at a service station we observe a sticker placed on the pump by a state official certifying that the pump has been tested and will deliver a true measure of quantities of fuel. This gas pump, therefore, has legal standing and is a legal dispenser of fuel to the public. In the same sense that the NGS realizes our national coordinate datum for the use of surveyors, a certified fuel pump is a realization of a physical measuring device into our legal system. However, the NGS datum and coordinates do not have a similar legal mechanism to support them in the legal system.

The surveyor's dilemmas associated with coordinate positions based on the new GNSS RTN networks are the following:

- What is the legal standing of the coordinates provided by the system?
- In the eyes of a court, what distinguishes the positions provided by the professional land surveyor from those of the layperson using the same system?
- What additional burdens of proof of position will a judge expect from a land surveyor as compared to the layperson?
- Do the current GNSS RTN network systems provide what U.S. land surveyors need for winning their cases in court?

With the advent of GNSS RTN, the coordinate positions of the RTN network base stations providing the GPS corrections will likely have to be certified under some form of the existing state and/or federal uniform weights and measures act(s) so that the public and the surveyors providing services for the public can rely on them. This process of making a coordinate a quantity governed by the weights and measures act has been carried out successfully recently in Australia and is a possible path that the U.S. land-surveying community may support here as well.

Survey control for land development, especially the boundary element, carried out by land surveyors has the extra dimension of having to be defensible within the legal system, which is a criterion over and beyond the application of the science of measurement. Survey monumentation from ancient times until very recently has been physical in character. From ancient times, the attributes of an adequate boundary monument are that they be identifiable (unique description), enduring (monument or natural feature), and defensible in chain of title and proof of possession. In the United States, the priority of calls in metes-and-bounds land boundary determination, according to Curtis Brown, are lines run by the creating surveyor, including all supporting infrastructure (corners set, monuments set, blazes); calls for set monuments at the time of survey; calls for adjoining parcels; calls for distances; calls for direction; calls for area, and, last and least, calls for coordinates.

Coordinates as boundary monuments in the United States are most frequently encountered in our Public Land Survey System (PLSS). Jerry Wahl, of the Bureau of Land Management, addressed the philosophy of proper coordinate use in the PLSS in the 1990s. His approach is based on the premise that coordinate (position) outputs can create an illusion of correctness because they bypass attention to the surveyor's normal methods of measurement analysis and consideration of error. In his view, coordinates are a *product* of measurement systems (instruments) that collect and process the raw data to create information by people operating the measuring and computing systems who vary in terms of education, training, and experience. Another major flaw in most coordinate outputs is that they are not normally accompanied by metadata and the data lineage as outlined in the next paragraph.

The land surveyor choosing to use coordinates to denote a boundary location needs to think ahead to the potential for defending them in a court of law. "The surveyor should remember that he may be called upon to explain and justify his operations before a court of law, and in order to be able to do that with confidence and assurance, he should always satisfy himself thoroughly that the evidence which he creates or uses in the course of his field operations is as good as the best that any other surveyor can point to" (Holloway, Alberta Surveyors presentation, 1952). There is a general consensus in the United States, Canada, and Australia that a professional surveyor's defense of position coordinates and survey control depends on creating a fabric of metadata and data lineage that includes who established the coordinates, what is known about the person's expertise and methodology, how the reliability of this coordinate record can be validated; identifies how the coordinates were established, what survey procedures were used, what survey control was used in the determination of the coordinate, and what datum the coordinates are on; verifies that the map projection reductions were properly and diligently applied; and identifies what monumentation or evidence was found, set, or recovered. These criteria also apply to the current work being carried out by the land surveyor. Wahl and others emphasize the importance of the surveyor being able to state in a court of law that, overall, the record gives you sufficient confidence that you have sufficient information to rely on it for restoration of the position or corner. The bottom line is that a position coordinate is only as good as the supporting positional references that accompany it.

The basis for legal position realization is the NGS CORS Network relational hierarchy of control. Scattered throughout U.S. law are sections of legal code in which public agencies have *enabling authority* to legislate use of coordinated monuments for certain activities. The hierarchy of this legislation can be found in the federal government, NGS Fiducial Network, NGS CORS, NGS Survey Control (monuments), BLM—PLSS Township and Range Position System, State and Municipal Government Survey Control (monuments), and State and Municipal GNSS RTN Networks. The status of coordinates used by land surveyors that are based on private RTN networks is not as clear at this time.

Martin Hale, of the geodetic survey for the State of Victoria in Australia, has developed a working “Formula for Legal Acceptance” for the guidance of land surveyors using coordinates for boundary determination. He specifies that the following elements must exist to establish a reliable fabric of practice to support GNSS RTN coordinates: there must be a national spatial information infrastructure (NGS), recognized CORS Networks, a weights and measures code that establishes a coordinate as a legal quantity (Regulation 13 NMR in Australia), certification as a land-surveying professional, and verifiable compliance with the industry practice guidelines. Hale asserts that careful attention to survey standards, quality assurance processes, workforce certification, professionalism, and adherence to professional best-practice processes ensures fewer legal challenges and more acceptance of this new mode of survey operations.

For land surveyors choosing to use coordinate corrections provided by a GNSS RTN network, the following minimum criteria must be provided by the network: continuous GNSS network solution quality assurance monitoring, real-time troposphere modeling, and real-time network model integrity (ionospheric and geoid errors) modeling. All network modeling needs to be carried out as a 3D network with real-time stability monitoring, periodic postprocessing of data, NTRIP monitoring, real-time multipath analysis, and independent automated RINEX files analysis (hourly).

In summary, the key asset of the legal position concept is location repeatability. This ensures the ability to navigate back to a previously located position, not just to a previous coordinate. This makes a legal position a hybrid of precision and accuracy while also providing a traceable line of evidence supporting the position location. This line of evidence does not exist in the ordinary operation of GNSS RTK unless an effort is made to record the raw observables, so the land surveyor must pay particular attention to this aspect in the design of the control survey.

OVERVIEW OF ADJUSTMENTS

As stated, the inevitability of errors in surveying measurements requires a means to eliminate them. As we have seen, random errors should follow a predictable pattern, and surveyors can use adjustments to remove these errors from the control network. If measurements are carefully made and if systematic errors are removed by calibrating the equipment and employing correct methods and procedures, the resulting random errors reveal themselves as angular and linear misclosures. If the misclosures are within tolerance, customary practice dictates that by adjusting the original observations the removal of these misclosures will cause the work to mathematically close upon itself.

Horizontal Adjustments

Adjustments of this type are made by surveyors for any or all of the following three reasons:

1. To distribute errors so that the measurements will mathematically close
2. To arrive at a set of horizontal positions that are closer to the truth
3. To determine the accuracy of each individual horizontal position

With increase in property values, these three reasons become increasingly important to ensure that a mathematically sound strategy for traverse adjustment exists. If the traverse consists of a simple loop, the horizontal misclosure is small, there is no desire to be closer to the truth, and the value of the accuracy for horizontal position is not desired, a case can be made for not making an adjustment.

However, most traverse control for land development projects consists of multiple cross-loops within the main loop for either data gathering or construction layout. The least squares method of adjustments is the only mathematically rigorous way of adjusting this type of traverse.

Angular Adjustment

For traverses, the traditional adjustment process contains two steps, angular and linear adjustments. A closed traverse, by definition, is one that closes upon itself or on a line of known azimuth or bearing. This formula is commonly used by field personnel to check their angular closure before leaving the field to ensure that their angular measurements do not contain a blunder. For a traverse that closes upon an external reference of known azimuth or bearing, the angular error equals the observed azimuth or bearing minus the known azimuth or bearing. For a traverse that closes upon itself, the angular error is determined by the following formula: the sum of the interior angles equals $(n - 2)180°$, where n equals the number of traverse angles in the loop. As an illustration, the sum of a five-angle traverse equals 540°02′. The formula states that the sum should be 540°. Therefore, the angular misclosure equals 02′.

Error of Closure

Since the advent of modern computers, traverses are computed using coordinates, as opposed to latitudes and departures. The reciprocal of the amount of linear misclosure divided by the length of the traverse is called the *error of closure* and is stated as a ratio. For example, if the linear misclosure of a traverse is 0.484 feet and the length of the traverse is 9,551.45 feet, the error of closure will be expressed as 1/0.00005, or approximately 1:19,740. This is commonly stated as 1 in 19,740 or 1 part in 19,740 parts. Simply stated, this means that, due to the accuracy with which the traverse was performed, if the traverse were 20,000 feet in length, there would be a horizontal error of 1 foot.

Many states still require surveyors to publish their misclosure as part of a survey. This is not appropriate to a least squares adjustment but can be done by such software as illustrated in the STARNET printout. By using certain settings and placing a “T” code in front of observation lines, the software will compute a closure in the traditional sense, then recompute data using mathematically rigorous least squares.

Traditional Methods of Horizontal Adjustment

Traditionally, surveyors have made traverse adjustments using the *arbitrary method,* the *compass rule,* the *transit rule,* or the *Crandall method.* As the name implies, the arbitrary method allows the surveyor to adjust the traverse by distributing the angular and/or linear errors among the setups where he or she thinks they were most likely to have occurred. For instance, if a portion of a traverse consists of good setup conditions (that is, good angular geometry) and long and clear sight distances, and a portion of the traverse is down a creek with short backsight and foresight distances or other poor setup conditions, the surveyor, using discretion, can distribute the misclosure errors by adjusting the observations where he or she thinks the errors were most likely to have occurred. In this case, adjustments are made to the setups along the creek. Many surveyors in the past favored this method because it allows for the use of professional judgment. Even so, it does not provide any assurance that the corrections were applied to the needed stations. By careful weighting of observations in a least squares adjustment, professional judgment can be input into the process while simultaneously obtaining a rigorous mathematical proof of the outcome of assumptions. (See Figure 12.15.)

Vertical Adjustments

Much as with horizontal adjustments, the most common method of adjusting level loops is to proportion the closing error equally to each turning point along the level run. However, the best method of adjustment requires knowledge of the distances between each turn. For this reason, the three-wire level procedure, because it supplies these distances through the use of stadia intercepts, is the easiest to adjust. The formula is:

$$\text{Correction to each turn point} = \left(\frac{\text{Distance start}}{\text{Total loop distance}}\right) \times \text{total vertical misclosure} \qquad (12.2)$$

The following level loop with a source benchmark elevation of 500.00 illustrates this principle. Note that the misclosure is positive in value, thereby requiring that each individual correction be subtracted from the unadjusted (or observed) elevations. Also note that this example does not meet third-order vertical closure requirements, which state that the allowable error shall not be more than 0.05 feet in 1 mile. See Table 12.2.

```
Traverse Closures of Unadjusted Observations
============================================
(Beginning and Ending on Adjusted Stations)
(Unadjusted Bearings and Distances Shown Reduced to Grid)

TRAVERSE 1
Error Angular   = 33.00 Sec, 4 Angles, 8.25 Sec/Angle
Error Linear    = 0.0473 S, 0.0063 E
Horiz Precision = 0.0477 Error in 1517.6494, 1:31817,
31.43 PPM

From      To        Unadj Bearing      Unadj Dist
100       103       S89-31-05.66E BS
100       101       N32-56-28.95W        365.8301
101       102       N70-01-26.83E        592.4457
102       103       S23-09-16.40E        559.3735
103       100       N89-31-05.66W FS
```

FIGURE 12.15 Traverse closures of unadjusted observations.

TABLE 12.2

STATION	ELEVATION	OBSERVED ELEVATION	DISTANCE FROM START	CORRECTION	ADJUSTED ELEVATION
B.M.	500.00				
T.P.		505.15	2000 feet	–0.028	505.122
T.P.		511.23	3500 feet	–0.049	511.181
T.P.		502.87	4500 feet	–0.063	502.807
B.M.		500.07	5000 feet	–0.07	500.00
Misclosure		+0.07			

Least Squares

Most traditional methods of adjustment rely on equal proportioning, intuition, or experience to remove the inevitable errors that result from survey measurements. Thanks to powerful and affordable personal computers and, more important, easy-to-use and affordable software, there is no reason why the land development surveyor cannot make use of least squares adjustments.

It is a superior adjustment method that also allows the simultaneous adjustment of multiple loop traverses. In addition, it provides a statistical measure of accuracy based on positional tolerance that is preferable to classifying a survey by proportional closure accuracy and allows the integration of observation data from both conventional and GNSS sources.

True least squares for all the data (loops and cross-loops simultaneously) works by deriving a solution that minimizes the sum of the squares of the residuals. It does this by minimizing the variation between the field observations and the final adjusted observations derived through a technique known as *variation of coordinates*. It also allows the surveyor to combine the known accuracy of the instruments with the field conditions that existed when the measurements were taken. Least squares will then use this information to provide an adjustment that closely reflects the actual position of the located points, all the while adjusting the coordinates the absolute minimum amount necessary.

Accuracy and precision should be the ultimate goal. Least squares allows statistical adjustment, thereby providing the best possible estimate of the true position of the points located, provided the blunders and systematic errors have been removed. The obvious intent should be to perform an adjustment that makes the smallest possible changes to the angle and distance measurements, preserving the surveyors' original observations as much as possible. Classification of a traverse by closure is fine for an indication of the accuracy of the traverse as a whole, but it will not indicate where the traverse points really lie or what could be done to improve the traverse. Least squares provides a superior adjustment based on a statistical analysis of the data and varying the coordinate values of the least amount, resulting in a best fit of the data. Least squares provides positional tolerance information based on a 95 percent confidence level. This means that the surveyor can say, with a 95 percent level of certainty, that the points he or she has located fall within an ellipse of certain dimensions.

If a surveyor wishes to use the manufacturer's specifications for the plus-or-minus uncertainty in the mean of a direct and reverse measurement, he or she can do so. But if the surveyor wishes to change the weights (confidence) based on his or her knowledge of actual field conditions, the program allows it. An example of a situation using a conventional instrument would be where the surveyor would want to weight an angle measurement that might be the case of a poor (unstable) setup, a short backsight, objects on a line that might bend the line of sight, or other field conditions that the surveyor would know about that would cause a particular measurement to be less accurate than others.

Redundant measurements to the same point from different setups result in the most accurate adjustment. Instead of simply establishing traverse points so that the backsight and the foresight can be seen, the proper use of least squares encourages these points to be placed in such a way as to allow maximum intervisibility between all setup points. The redundancy provided by more observations results in a better solution.

The least squares adjustment provides two additional tools for surveyors. The preanalysis option allows users to input approximate coordinates of the proposed traverse stations. The program then suggests additional stations and/or measurements that result in a stronger, more accurate network. These approximate coordinates can be digitized from a quad sheet or other map or derived by scaling and protracting. The preanalysis option detects geometric weaknesses in the proposed traverse. It even tells users if they are doing more work than necessary to achieve the desired level of accuracy.

Another powerful feature is blunder detection. Least squares software analyzes the data from the traverse and detects possible blunders. In the event a survey fails to meet the minimum requirements for accuracy, this feature alone indicates the stations where the blunders in measurement most likely occurred. Because the program makes a simultaneous adjustment and all of the stations are interrelated, it might tell the user to look at a station that is one or two traverse points away from the real culprit. How many times has a surveyor gone back to the field to re-turn angles, not having the slightest idea where the angle bust occurred? If the surveyor fully utilizes the capabilities of the least squares method, field techniques can be learned that will result in higher-quality surveys.

NGS has pioneered the use of total stations to perform first-order level loops, and even the less precise total stations provide enough accuracy for trigonometric (trig) levels to aerial targets and certain construction layout tasks. With this increased use comes a need for a method to adjust both the horizontal and vertical measurements of any traverse, applying the same statistically proven adjustment techniques to both. Level circuits containing multiple loops can be easily adjusted by least squares. Users can assign different weights (standard errors), thus allowing the leveling of observations of varying accuracies to be simultaneously adjusted, as would happen if measurement were collected by different equipment at different times. The program works with distances between turns or the number of turns to assign weights automatically.

OVERVIEW OF A TYPICAL LEAST SQUARES ADJUSTMENT OF CONVENTIONAL SURVEY DATA

A least squares adjustment output is herein interwoven with a brief explanation of what the major output components represent. The software used is StarNet Least Squares by SoftPlus Software. A demonstration version of this program, which is the full software restricted to 10 stations but with unlimited observations, is available free on request. The software comes with an excellent tutorial. The example included here can be run in the demonstration package.

We begin with the input data for a small (four-station) traverse. Many pieces of quality assurance data are available in this input file, which is created by the software from a data collector raw file. Note that the metadata and data lineage begin here and include the software and version of software used for the processing. Once processed, this brief text file results in an extensive and rigorous adjustment of data with many quality assurance outputs. These outputs far exceed anything available in older methods.

Numerous inline codes are available to control processing of the data. In this case, although 3D coordinates were input, this was overridden by the file being set for 2D (.2D) processing. Also, the .PTOL with point pairs has been set to meet ALTA/ACSM style specifications and the T code has been used to set observation processing to compute an initial traverse proportional ratio closure to comply with Virginia state land survey requirements. Two coordinates that were obtained using GNSS methods were held fixed, and this is indicated by the use of exclamation marks for each component of N, E, Z (! ! !). (See Figure 12.16)

```
# STAR*CG Version 1.0.1
# Copyright 2006 Starplus Software, Inc.
# Input Field File : C:\Hamilton Starnet\HDSA1003 edited.RAW
# Date Processed  : 10-12-2007 13:02:01
.2D
.ORDER AtFromTo
.SEP  -
.PTOL 101-103 100-102
# TRAVERSE
# HAMILTON DOMINION STATION
# 10-03-07
# HDSA1003 RAW
C 100 7101419.81700   11715153.28400   ! !   'GPS #100
C 101 7101726.84900   11714954.33400   ! !   'GPS #101
C 102 7101929.30000   11715511.13400         'GPS #102
# 10/03/07 10:52:01
TB 103
D 100-103                                      577.8620 'TRV103
T 100                     236-34-45.00         365.8405 'TRV101
# 10/03/07 10:56:04
D 101-100                                      365.8348 'TRV100
T 101                     282-58-04.00         592.4624 'TRV102
# 10/03/07 11:12:48
```

```
#D 101-100                                      365.8349 'TRV100
#T 101                    282-57-23.00          592.4622 'TRV102
# 10/03/07 11:16:50
D 102-101                                       592.4582 'TRV101
T 102                     266-49-25.00          559.3893 'TRV103
# 10/03/07 11:26:19
D 103-102                                       559.3955 'TRV102
D 103-100                                       577.8593 'TRV100
TE 103                    293-38-19.00          100      'TRV100
```

Under Adjustment Options, users can select the type of adjustment desired—data check, full adjustment, blunder detect, and so on. Users can also select whether the network is 2D or 3D. One of the most powerful features of the program is its ability to handle state plane coordinates. Users can input the state number and zone, an average project elevation (or elevations, fixed or free, at each traverse station), and the geoid separation value. The geoid separation value can be obtained from NGS or from the NGS State Geodetic Advisor. Using this information, the program automatically computes the combined scale factor and processes the input data. The field crew can use this combined scale factor when staking out, for instance, by inputting the value into a data collector. The data collector can then apply the factor to each distance measurement, thereby saving time for the field crew. The program will accept local coordinate systems, NAD 27 or 83 Mercator or Lambert state plane coordinates, and UTM coordinates.

Next, users input the default standard errors for the equipment they are using. Many users simply input the manufacturer's stated accuracy for these values—for example, 5 mm and 5 PPM for a standard EDM. As mentioned under "Types and Sources of Error," if the input file consists of angles (as opposed to directions), then the NGS procedure of multiplying the manufacturer's stated accuracy by $\sqrt{2}$ should be used. This establishes the a priori (before adjustment) value for the observations and represents the user's estimate of the accuracy of the equipment.

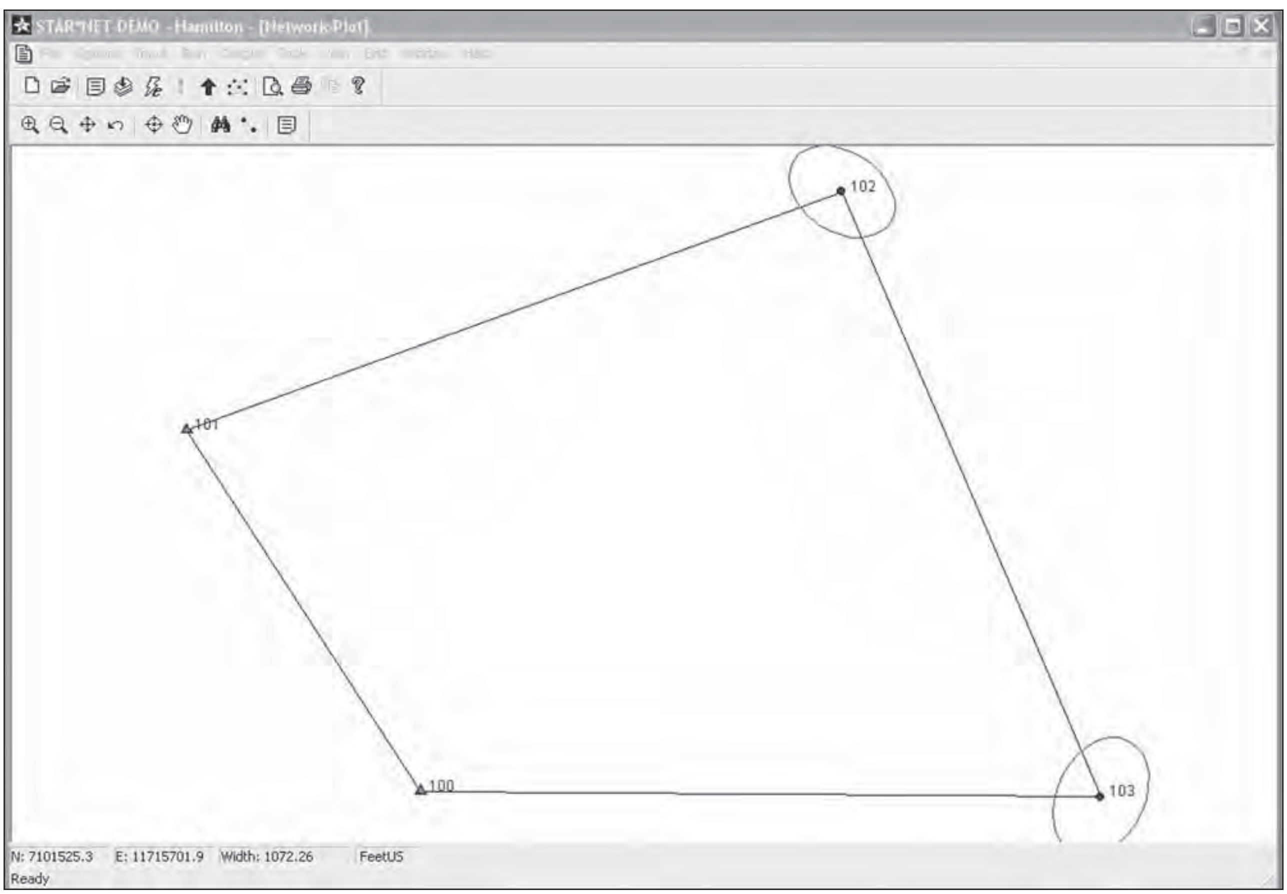


FIGURE 12.16 Plot of simple four-station 2D network with two fixed controls from GNSS.

The weight of an observation can be thought of as a measure of its precision. More precise measurements have larger weights and will have more influence in the adjustment. Generally, observations with smaller weights will be allowed to change more—that is, they are given larger residuals by the adjustment.

```
STAR*NET-PRO Version 6.0.35
Copyright 1988-2006 Starplus Software, Inc.
Licensed for Use by Joseph Betit
Run Date: Fri Oct 12 2007 13:52:05
```

Summary of Files Used and Option Settings

```
=========================================
```

Project Folder and Data Files

```
Project Name            HAMILTON
Project Folder          C:\DOCUMENTS AND SETTINGS\...\LEESBURG\HAMILTON
Data File               List 1. HDSA1003 edited.dat
```

Project Option Settings

```
STAR*NET Run Mode:                     Adjust with Error Propagation
Type of Adjustment:                    2D
Project Units:                         FeetUS; DMS
Coordinate System:                     Lambert NAD83; VA North 4501
Default Project Elevation:             500.0000 FeetUS
Geoid Height:                          -30.0000 (Default, Meters)
Longitude Sign Convention:             Positive West
Input/Output Coordinate Order:         North-East
Angle Data Station Order:              At-From-To
Distance/Vertical Data Type:           Slope/Zenith
Convergence Limit; Max Iterations:     0.010000; 10
Default Coefficient of Refraction:     0.070000
Create Coordinate File:                Yes
Create Geodetic Position File:         No
Create Ground Scale Coordinate File:   No
Create Dump File:                      No
```

Instrument Standard Error Settings

```
Project Default Instrument
Distances (Constant) :                 0.030000 FeetUS
Distances (PPM) :                      0.000000
Angles:                                4.000000 Seconds
Directions:                            3.000000 Seconds
Azimuths & Bearings:                   4.000000 Seconds
Centering Error Instrument:            0.010000 FeetUS
Centering Error Target:                0.010000 FeetUS
```

As discussed under "Adjustments," users can assign weights to the observations or make the assumption that all observations are equal with respect to their accuracy. Because the program renders an adjustment regardless of the input values, many users hold the coordinates for two points (or one point and an azimuth) fixed and run what is called a *minimally constrained* adjustment (see preceding section with input file). This trial adjustment can aid users in identifying blunders in the observation. Next, users can fix the values for all points or azimuths that are to be held fixed and rerun the adjustment. Remember that this is the opportunity for surveyors to express their level of confidence in the measurements by weighing the observations. Most users assume that all observations are equal in accuracy and allow the program to use the default values for weighing.

Users can control the number of *iterations* the program uses to perform the adjustment by specifying the convergence limit. If the change in the total sum of the squares of the standardized residuals is less than this convergence limit, the adjustment is said to have converged, and iterations will stop.

After the adjustment has run, users are presented with a statistical summary containing some of the most useful and important information about the adjustment. The total number of observations defines the number of condition equations to be solved. All observations that have not been fixed are considered to be free, that is, adjustable. The number of unknowns equals the number of adjustable coordinate components. Each 2D station contributes two unknowns, as each 3D station contributes three. The *degrees of freedom* equal the number of condition equations minus the number of unknowns. Using the approach of giving the program all possible pieces of data, some users include every observation in the input file—for example, foresight and backsight distances and foresight and backsight zenith angles. This approach actually inflates the degrees of freedom that affect the chi-squared test, and even though the final adjusted coordinates will be the same, error propagation will be influenced, as will the chi-squared test. The result of this approach is that otherwise good surveys might fail the chi-squared test (described later) because of too many degrees of freedom. This is an inherent problem with the chi-squared statistical test, which is simply one indicator of the quality of the adjustment. Assessment of a least squares adjustment requires professional assessment of a number of factors contained within the output—a single measure is seldom satisfactory to rely on as a definitive measure of quality. Despite the possible effect on the chi-squared test, redundant observations are good procedure. They always add to the quality of the QA/QC process and are easily accommodated by all quality least squares software packages.

```
Summary of Unadjusted Input Observations
========================================

Number of Entered Stations (FeetUS) = 3

Fixed Stations            N                  E            Description
     100             7101419.8170       11715153.2840       GPS #100
     101             7101726.8490       11714954.3340       GPS #101

Free Stations             N                  E            Description
     102             7101929.3000       11715511.1340       GPS #102

Number of Measured Angle Observations (DMS) = 4

 At        From        To         Angle          StdErr        t-T
100         103        101     236-34-45.00      11.28        -0.04
101         100        102     282-58-04.00       9.75         0.02
102         101        103     266-49-25.00       8.30         0.04
103         102        100     293-38-19.00       7.62        -0.02

Number of Measured Distance Observations (FeetUS) = 8

From           To          Distance          StdErr         Comb Grid
 100           103         577.8620          0.0332         0.9999717
 101           100         365.8348          0.0332         0.9999717
```

100	101	365.8405	0.0332	0.9999717
102	101	592.4582	0.0332	0.9999719
101	102	592.4624	0.0332	0.9999719
103	102	559.3955	0.0332	0.9999717
103	100	577.8593	0.0332	0.9999717
102	103	559.3893	0.0332	0.9999717

```
Adjustment Statistical Summary

=========================================

Iterations =              2

Number of Stations =      4

Number of Observations =  12
Number of Unknowns =      4
Number of Redundant Obs = 8

Observation         Count of StdRes        Sum          Squares Factor        Error
Angles                    4                3.341                              1.119
Distances                 8                1.709                              0.566

Total                     12               5.050                              0.795

The Chi-Square Test at 5.00% Level Passed
Lower/Upper Bounds (0.522/1.480)
```

The next item the summary lists is the sum of the squares of the *standardized residuals* for each data type. The standardized (or normalized) residual is the result of dividing the residual for each observation by its standard error. This is done because although the residual is the variance between the observed value and the value that best fits into the network, the standardized residual takes into account the geometry of the survey network. Because of this, it is a good check for blunders. If the value is less than 1, the data type actually fits better than estimated results. If greater than 1, it is a poor fit. Any value greater than 3 is flagged as an indication that there is something wrong with that data type. The next part of the summary lists the *error factor* for each measurement type. The error factors are affected by the number of observations and are a good indication of how well each data type fits into the adjustment. The error factors should be roughly equal and should range from 0.5 to 1.5. If one is much greater than another, then a problem could exist with that measurement type. Remember that unless the user weights measurements, the adjustment will assume that the data types are equal in precision. Large error factors indicate an error in the input data, a systematic error, or input standard errors that are unrealistically small. Also, because of the interconnection of stations, a large error in one data type can influence the error factor of others. If the user has established the input standard errors correctly and has no systematic errors or blunders, the *total error* factor should be close to 1. This is an indication of correct input data assumptions. The total error factor is calculated by dividing the square root of the sum of the squares of the standardized residuals by the number of redundancies. The total error factor is also referred to as the *reference factor* or the *standard error of unit weight.*

Adjusted Station Information

==

Adjusted Coordinates (FeetUS)

Station	N	E	Description
100	7101419.8170	11715153.2840	GPS #100
101	7101726.8490	11714954.3340	GPS #101
102	7101929.2649	11715511.1357	GPS #102
103	7101414.9584	11715731.1013	TRV103

Adjusted Positions (FeetUS)

Station	Latitude	Longitude
100	39-08-45.341559	77-40-52.166887
101	39-08-48.393640	77-40-54.657340
102	39-08-50.345111	77-40-47.567066
103	39-08-45.242536	77-40-44.833460

Convergence Angles (DMS) and Grid Factors at Stations
(Grid Azimuth = Geodetic Azimuth - Convergence)
(Elevation Factor Includes a -30.00 Meter Geoid Height Correction)

	Convergence	------- Factors -------			
Station	Angle	Scale	x	Elevation	= Combined
100	0-30-39.80	0.99999085		0.99998080	0.99997165
101	0-30-38.24	0.99999099		0.99998080	0.99997178
102	0-30-42.67	0.99999108		0.99998080	0.99997187
103	0-30-44.37	0.99999085		0.99998080	0.99997164
Project Averages:	0-30-41.27	0.99999094		0.99998080	0.99997174

Adjusted Observations and Residuals

==

Adjusted Measured Angle Observations (DMS)

At	From	To	Angle	Residual	StdErr	StdRes
100	103	101	236-34-33.23	-0-00-11.77	11.28	1.0
101	100	102	282-57-52.04	-0-00-11.96	9.75	1.2
102	101	103	266-49-18.48	-0-00-06.52	8.30	0.8
103	102	100	293-38-16.24	-0-00-02.76	7.62	0.4

```
Adjusted Measured Distance Observations (FeetUS)
```

From	To	Distance	Residual	StdErr	StdRes
100	103	577.8541	-0.0079	0.0332	0.2
101	100	365.8652	0.0304	0.0332	0.9
100	101	365.8652	0.0247	0.0332	0.7
102	101	592.4695	0.0113	0.0332	0.3
101	102	592.4695	0.0071	0.0332	0.2
103	102	559.3869	-0.0086	0.0332	0.3
103	100	577.8541	-0.0052	0.0332	0.2
102	103	559.3869	-0.0024	0.0332	0.1

Adjusted Bearings (DMS) and Horizontal Distances (FeetUS)

```
=========================================

(Relative Confidence of Bearing is in Seconds)
```

From	To	Grid Bearing	Grid Dist	95% RelConfidence		
			Grnd Dist	Brg	Dist	PPM
100	101	N32-56-32.47W	365.8548	0.00	0.0000	0.0009
			365.8652			
100	103	S89-31-05.66E	577.8377	20.22	0.0455	78.6907
			577.8541			
101	102	N70-01-19.60E	592.4529	17.19	0.0450	75.9109
			592.4695			
102	103	S23-09-21.89E	559.3711	19.72	0.0426	76.1162
			559.3869			

The program also applies a test to the adjustment by comparing the total error factor against the assumed value. This test, called the *chi-squared test,* checks the validity of the weighing observation. If this value is significantly greater than 1.0, then there is some problem with the adjustment—either a systematic error, a blunder, or weakness of network geometry. The chi-squared test is performed at a 5 percent level of significance. This means that there is a 5 percent chance that the adjustment will pass the test with a total error factor that is greater than 1.0. If the value is significantly less than 1.0, then the input standard errors have been overestimated. While this may not affect the final coordinates, the result of the chi-squared test is an error propagation in that portion of the adjustment and will increase the size of the error ellipses.

The *error ellipse* (not illustrated in this output) computed for each station represents the size of the ellipse for which there is a 95 percent certainty that the point actually lies within the ellipse. As indicated by the program, the semimajor and semiminor values are ground dimensions across half of the ellipse.

The absolute dimensions provide a measure of positional accuracy. Points with larger ellipses are weaker than those with smaller ellipses. The shapes and orientation indicate how the network can be strengthened. An elongated ellipse indicates that there is a larger error in one of the coordinates for that station and that perhaps an additional distance or angle measurement is needed to that station. A large but circular ellipse indicates that the northings and eastings are balanced for that point, but more accurate measurements are needed, or additional measurements are needed, from other stations. If many ellipses are elongated and all point in the same direction, the network is unbalanced along that direction. This might be the result of an azimuth deficiency that allows one side of the network to rotate slightly. An additional control point or observed azimuth will help alleviate this condition.

The program also develops *relative error ellipses* to express the relative position of two points. Two points with large station ellipses may actually have a small relative ellipse between them, meaning that their absolute positions in the survey are weak but that they are correlated with each other and move together. The length of the relative ellipse projected onto the line between the two points is a measure of the precision of the distance between the two points. The length of the relative ellipse perpendicular to the line is a measure of the precision of the bearing between the two stations. The plus-or-minus relative errors of the bearing and distance for each course are based on the values contained in its associated relative error ellipse. The distance precision is computed by dividing the relative distance error by the length of the line.

The next section illustrates accomplishing two legal requirements for boundaries. The first is a state land surveying legal requirement for showing a closure for the traverse (see preceding input section for more details) and the ALTA/ACSM land title survey requirement for Positional Tolerance of Closure between specified pairs of points (see the section on ALTM/ACSM specifications for additional details).

```
Traverse Closures of Unadjusted
Observations

=========================================

(Beginning and Ending on Adjusted Stations)
(Unadjusted Bearings and Distances Shown Reduced to Grid)

TRAVERSE 1
Error Angular = 33.00 Sec, 4 Angles, 8.25 Sec/Angle
Error Linear = 0.0473 S, 0.0063 E
Horiz Precision = 0.0477 Error in 1517.6494, 1:31817, 31.43 PPM

From        To         Unadj Bearing        Unadj Dist
100         103       S89-31-05.66E BS
100         101       N32-56-28.95W           365.8301
101         102       N70-01-26.83E           592.4457
102         103       S23-09-16.40E           559.3735
103         100       N89-31-05.66W FS

Error Propagation

=========================================

Station Coordinate Standard Deviations (FeetUS)

Station          N              E
100          0.000000      0.000000
101          0.000000      0.000000
102          0.017852      0.020638
103          0.023098      0.018630

Positional Tolerance Check (FeetUS)
Allowable Tolerance = 0.0700 + 0 PPM
Tolerance Check Confidence Region = 95%
```

Stations		Horizontal	Semi-Major-Axis		Ratio
From	To	Distance	Actual	Allowed	Actual/Allowed
100	102	622.5713	0.0548	0.0700	0.7835
101	103	837.0443	0.0596	0.0700	0.8507

```
Connections Checked = 2
Number of Failures = 0

                        Elapsed Time = 00:00:00
```


ACKNOWLEDGMENT

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CHAPTER 13

BOUNDARY SURVEYS FOR LAND DEVELOPMENT

Gary Kent, LS

Updated/Revised: Karen Brill, PS

INTRODUCTION

Property Surveying

Land surveying is the art and science of measuring distances and running lines on the surface of the earth. One of the purposes of land surveying is to determine the boundaries and ascertain the areas of tracts of land. Fixing the position of corners, monuments, lines, and boundaries requires that the surveyors use a variety of instruments and correctly apply a variety of principles of law.

Reproducing previously established boundary corners and lines in their intended legal and physical positions is a matter of determining the intent of the original survey or other written documents used to first establish them. This seems trivial at a glance, but upon examination it is evident that such a task requires the experience, perseverance, and reasoning of an expert detective. Research is the key for a successful boundary retracement. That research includes gathering evidence, interpreting that evidence in light of conditions at the time of creation of the boundary, and, finally, re-creating the location of the boundary on the ground as it exists today. Consideration of written evidence is of utmost importance, but the physical evidence and oral testimony related to interpreting the written evidence are crucial to complete research.

Research for boundary surveys begins by gathering property descriptions, tax maps, roadway plans, zoning maps, easements, and other related information. Gathering of this information begins when the client and the engineering or surveying firm enter negotiations for the future development of a tract of land. An important depository of research information is the local courthouse. Local utility companies often can provide valuable maps and information. State and federal agencies maintain valuable land information. Title insurance companies can play a role in providing deeds, easements, other record title information, and previous surveys of the subject property or adjoining properties; however, title insurance companies often do not research far enough back in time to return to the original survey.

Existing maps or plats of the land provide visual support for reaching conclusions that ultimately result in re-creating boundary locations. Maps may be found during the search of land records and from the evidence found during the field survey. Plotting individual deeds, patents, and grants provides pieces of a jigsaw puzzle. When the pieces of the puzzle fit together and form a logical composite map, this may provide some clues to successfully interpret land ownership and boundary location.

Two of the primary systems that form the basis of land descriptions in the United States are the metes-and-bounds system and the Public Land Survey (PLS) System (later called the General Land Office, or GLO System). There are other systems that have historically been used in different areas within the United States; therefore, surveyors should familiarize themselves with the system that applies to the particular project. These systems have an impact on interpretation of evidence gathered in the research process.

Functions of the Property Surveyor

Determining the location of boundary lines receives high priority on the list of steps in planning and implementing land development projects. The professional surveyor thus becomes a major part of the team of professionals necessary for carrying land development projects to successful completion. The surveyor's knowledge and skills must be broad in scope yet particularly specialized in the intricacies of surveying.

Surveying professionals must be well versed in real property law. In resolving boundary locations, surveyors are required to interpret and apply legal principles. Surveyors must have knowledge of both the planning and the engineering aspects of a project in order to provide, through the survey, the proper information for layout and design of lots, streets, and utilities. In short, surveyors should understand the entire land development process.

For many development projects that lie away from urban areas, surveyors might fill the roles of many professionals. In this way, surveyor could be compared to the doctor who is a general practitioner. Most often, land development takes place in an urban setting, but this situation does not relieve the surveyor of assigned general responsibilities in the project. In this situation the surveyor's greater role, however, becomes that of a specialist. The tools are those afforded by the latest in technology. Computers, electronic measuring devices, global positioning systems, aerial photogrammetry, and total station equipment have all but replaced the slide rule, transit, and steel tape of only a few years ago.

Mathematics, statistics, and electronics have become increasingly important to professional surveyors today. While the survey tools continue to advance, it is increasingly important that surveyors keep in touch with the past, as the very act of boundary surveying requires following in the footsteps of predecessors. To accomplish this, surveyors must, in essence, wear the shoes they wore. Understanding how previous determinations were made requires that classic or traditional terms and tools—the Jacob staff, compass, perches, arpents, varas, poles, rods, and Gunter's chains—remain a part of modern survey working vocabulary.

Surveyors must use their knowledge and training to perform the duties associated with the profession. These include duties to the public and duties to the client. The first category of duties to the public includes maintaining qualifications (licenses) and abilities through training and continuing education. It also includes limiting the survey practice to those areas of expertise where the surveyor is competent.

It is the surveyor's duty to avoid creating or propagating boundary disputes if possible. Often through discussions with adjoining owners and the client, the surveyor can arbitrate disputes and bring parties to equitable solutions while avoiding costly legal actions. Of course, the surveyor should be cognizant that professionals with legal training (i.e., licensed attorneys) should be consulted when issues arise.

Surveyors must keep their duties to the public and to the client in perspective. Most important in this regard is the surveyor's advice to the client. Clients should be made aware of the function and limitations of surveyors. This discussion should include a clear explanation of the document research process related to the survey. Clients should know that surveyors must consider and inquire into all the facts of record and those existing in the field. Surveyors should advise clients that neither the opinion nor the survey of a surveyor is conclusive in the determination of boundaries. Clients should be advised that it is the surveyor's duty to gather facts and interpret them based on the rules of evidence, but that the final disposition of boundary location and property ownership lies with the court.

Before proceeding with the project, it is advisable to reach a clear understanding with the client on the terms under which the work will progress. A contract should be prepared for each project before beginning work. It should include a detailed scope of all services to be performed and should provide for means of payment. When the client understands the role of the surveyor in the development process and an agreement is reached concerning a contract to proceed, the actual research begins.

The date of the last transfer of the land must be determined. All information obtained at this stage reduces the time spent in searching records later. This information forms the basis on which future research and analysis of land ownership rests.

If available, obtain an abstract of the property that is to be included in the proposed land development project. The abstract summarizes the record history of the documents affecting the title or land ownership. The abstract includes, in chronological order, all recorded grants, deeds, easements, wills, and other information such as deeds of trust, tax liens, assessments, and any other encumbrances of record affecting the property. Surveyors should not rely entirely on the abstract, as it does not relieve them of the obligation to perform research.

The additional survey requirements typically associated with development projects, especially those involving subdivisions and land consolidations, greatly increase the detail that must be obtained during the boundary survey. Surveyors should point out to clients that the necessity for greater detail, precision, and accuracy may directly increase survey costs. The same care and thoroughness should be taken whether performing a rural or an urban boundary survey, regardless of the likelihood of development. An accurate boundary survey is a critical first step in the land development design process and, pending the survey results, it may influence a client's perspective (go or no-go decision) on a given property.

Legal Descriptions

The part of the deed devoted to the physical location of the real property is known as the *legal description*. A general definition of a legal description can be stated as "those words and maps or plats that uniquely delineate the tract from any other." The description must be written in such a manner that it will stand any test under law and litigation.

Such descriptions can be formed in various ways. Words describing lines composed of bearings and distances and calling for monuments of one type or the other are *metes-and-bounds* descriptions. Some descriptions refer to tracts that are recorded in the public records. Other types of descriptions are used for particular situations such as strip descriptions for rights-of-way for roads, power lines, and other utilities. The thread common to all of them is that each describes a specific parcel of land that cannot be applied to another parcel. The surveyor should write a legal description that is as brief as possible while maintaining clarity, completeness, and accuracy. Incomplete, inaccurate, and unclear descriptions result in boundary disputes, which may turn into title disputes later.

The description is composed of three parts, and, in some cases, augmenting clauses are added. These parts are the caption, the body, and the habendum, which includes qualifications such as exceptions and reservations. Each part of the description serves a definite purpose.

The caption establishes the general placement of the subject property and limits title in the remainder of the description to that general area outlined in the caption. A typical caption in a description could read as follows: "that certain tract or parcel of land, situated at or near City, District, County, State and being more particularly described as follows."

The body of the description generally follows the caption. A typical body in a colonial state deed description might read as follows: "Beginning at a set stone at a corner of rail fence on the old baggage road, and running with the said road to the Noah D. Johnson line, and with said line to the John C. Williams line, thence with the Williams line back to a set stone corner on said John C. Williams line, thence a straight line to the beginning, containing three (3) acres, more or less." Describing parcels within land subdivisions employs the use of reference to a subdivision map of record. Such a description follows:

> Being situated at or near City, County, State, and being more particularly bounded and described as follows, to-wit:
>
> Lot No. 98 of the Forest Hills Subdivision, as the same is shown and designated on a map or plat thereof which is of record in the office of the Registrar of Deeds of (*County*), (*State*) in Map Book 8, at page 67.

The third part of the description, the habendum, does not follow any particular arrangement. These clauses may except some part of the conveyance or reserve some part generally for the grantor. Qualifying clauses often follow the body of the description. Such a clause might read: "There is excepted and reserved from this conveyance a 10 foot lane, which lies on the western boundary of the property herein described, which serves as access and egress to Donald Thompson and this reservation is for the benefit of the owners of the property presently owned by Donald Thompson and to the successors in title to Donald Thompson."

For a complete discussion on writing descriptions as well as a study of the various types of descriptions encountered by surveyors, reference is made to Gurdon Wattles's book *Writing Legal Descriptions in Conjunction with Survey Boundary Control* (1976).

SURVEYS FOR BOUNDARY LOCATION

The land description contains the written instructions that demonstrate the original intent of the conveyance. Except in explicit situations, any retracement of the property must be based exclusively on the record description.

When the legal description of the property is prepared from a survey preceding that description, that survey is called the *original survey*. Any surveys made after the writing of the description are called *retracement surveys*. If the description of the site was prepared without benefit of a survey, then there can never be an original survey. The first survey made after a description is written without benefit of survey is called a *first survey*.

Original surveys should not be confused with first surveys. Although all original surveys are first surveys, a first survey is not necessarily an original survey. First surveys are not given the same standing in law as original surveys. This is because the intent of the parties to the transaction creating the description comes from the document containing the description. A first survey is only an *interpretation* of the original document. When original surveys exist, the intent of the parties is presumed to have come to the description through the survey. There are few rules in real property law more certain than that which states "original called-for monuments control over course and distance."

The surveyor's responsibility when making a resurvey is to recover or determine the location of the original monuments (if there were any) and, if there were none, to interpret the intent of the record description based on the best available evidence, then establish the corners and lines of the tract accordingly.

A boundary survey does not end with the establishment of the corners and lines of the surveyed parcel. The surveyor must also relate the surveyed lines to occupation and possession lines.

Encroachments and Gaps

Visible evidence of potential encroachments of any kind must be located and the history of the encroachment documented if possible. An encroachment may be defined as a trespass or the commencement of a gradual taking of possession or rights of another. Encroachments may take the form of walls, fences, buildings, or other structures representing occupation or possession, which extend onto another's title rights. Encroachments may lead to claims of unwritten rights such as adverse possession or acquiescence when the party whose land is encroached upon allows the encroachment to go unchallenged. Such an implied consent may cause loss of title through certain doctrines.

Often land contemplated for development comprises several smaller tracts, which are joined together to form a larger, more developable tract. In such a situation, it is important for the surveyor to confirm the contiguity of the parcels involved or to identify the existence of any gaps between the parcels. This is critical because the record title to such a gap may lie in the hands of some former owner rather than in the hands of the owner of the parcels being surveyed. Gaps can be as troublesome as encroachments if not identified and quantified before development actually begins.

Importance of the Survey in Land Development

In the land development process, the determination of tract location and geometry is of utmost importance. Surveys should resolve whether the written description and the physical possession on the ground agree. All future work related to development hinges on the initial survey work. Should an error occur in the survey, it will most likely manifest itself in later stages of the development process. It is conceivable that errors in the initial survey could lead to improper location of streets and other improvements and to incorrectly placed interior boundary lines. Errors such as these could bring on project delays, possible project shutdown, and redesign which inevitably cost both time and money. The results of poor judgment associated with boundary line location can be severe: clients lose confidence and can even pull or rescind work as a result.

Definite procedures, including such quality control tools as checkoff lists, are invaluable in helping to ensure consistency. No procedure or checklist, however, can substitute for diligent fieldwork procedures, common sense, and an intimate knowledge of survey law. Both the client and the surveyor must recognize that the results of any boundary survey can be challenged, as it is the province of the judiciary, ultimately, to determine boundary location. The surveyor supplies much of the evidence on which court decision is based.

When the development involves one or more loans, the lender typically requires certain assurances to be confident that its investment is as risk-free as possible. One of the tools to minimize risk is the ALTA/ACSM Land Title Survey. This type of survey is defined by a set of standards adopted and periodically revised by the American Land Title Association and the American Congress on Surveying and Mapping. The current version, as of the date of this publication, is the 2005 standard (see Appendix G).

The Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys outline the responsibilities of the surveyor in conducting a survey that will be used by the title company and lender in conjunction with the closing of a commercial loan on real property. The standards also outline the responsibility of the client or his or her representative with respect to providing complete sets of documents from the title research and as may otherwise be required by the surveyor to conduct a proper and complete survey. In addition, the optional checkoff items in Table A allow the client or lender to request additional information from the surveyor related to certain specific issues such as availability of utilities.

The ALTA/ACSM Minimum Standards call for the surveyor to resolve the boundary of the property in addition to providing comprehensive documentation of any facts on the ground or in the provided records that may be evidence of otherwise unknown or undisclosed title problems. Such facts might include, for example, gaps or overlaps with adjoiners, and potential encroachments and uses of the property by others. The disclosure of these facts allows the title company, lender, and buyer to weigh the associated risks and to negotiate or formulate appropriate resolutions to any issues that might have been found in the course of the survey.

Research of Land Records

The actual process of conducting research varies widely across different regions of the United States. In the metes-and-bounds states (being, generally, the original 13 colonies and the lands claimed by those colonies), surveyors are often expected to conduct their own complete title searches. Although some states permit more flexibility in the manner of procurement of title information, no state minimum standards exempt or relieve a surveyor of the burden of basic research.

The surveyor must seek out all information from public and private records that may be of benefit in performing the survey. Ideally this information is gathered and evaluated prior to commencement of the fieldwork. If not, additional trips to the field will be required as new pieces of evidence from the records dictate further field investigation.

Research information comes from a variety of sources. Typically, a visit to the county assessor and/or auditor (the name and function of county offices differ in various parts of the country) will help in the search for the record descriptions of the subject property and its adjoiners. Most county tax maps are geographically inaccurate, but they are useful in identifying the juxtaposition of subject and adjoining properties, roads, streets, and other features.

Once the names and property transfer dates are determined, a copy of the actual transfer document can normally be found in the county registry of deeds, county recorder's office, or clerk of the court. This office of public record varies from state to state.

All states allow for the recording of deeds when the transfer of real property takes place, and almost all such transfers by deed are recorded. These recordation statutes provide a means of giving notice of ownership of the estates disclosed in the recorded instrument. Unrecorded deeds or other instruments are generally valid only between the immediate parties. These recordation statutes are not applicable in cases of title acquired by unwritten means such as adverse possession.

The surveyor should make use of these depositories to obtain the deeds of adjacent property and check previous transfers of the subject property. Intentions as to boundary location must be obtained from the information at the time the lines and corners were created. Comparison of the deeds of the subject tract should be made with those of the adjoining property to determine whether conflicting calls exist.

The type or method of physical record keeping varies from county to county and state to state. Many continue to maintain their records as they have for 200 or more years, in transfer books, grantee/grantor index books, and deed record books, while many others have converted to microfilm or microfiche records. With the advent of affordable hardware and software for geographic information systems (GIS), many more populous counties are converting their current and new records to digital format, which is often available online in the courthouse or, in some cases, even remotely via the Internet.

However the physical records are kept, the depositories contain the index of all deeds and most of the other legal instruments or writings affecting real property. To use this information, one must be familiar with the system used to index these many thousands of documents. Generally, the indexes consist of two interdependent parts: the grantor (or vendor) index and the grantee (or vendee) index. The grantor is the party who sells the land; the grantee is the buyer.

Listings in these indexes are chronological by date of recording. Most states use this method of indexing and filing deeds. Although the details may vary somewhat from jurisdiction to jurisdiction, the basic information required for a title search is generally consistent no matter what the system. The surveyor needs to know either the name of the party who bought the property or who sold the property. Knowing both buyer and seller is even better, and this information is available from the transfer books mentioned earlier. In addition, knowing the approximate date of the transaction shortens the search process.

The actual process of checking the title begins with the name of the present owner in the grantee index. The grantor of this conveyance was the grantee of the previous conveyance. Looking each previous conveyance up in this manner results in the development of a chain of title for the property. Using this chain, a person familiar with reading and interpreting title documents can determine whether each person in the chain took title to the property in a regular manner without defect. The grantor's name, the type of instrument, and the book and page of the actual recorded document involved in the particular transaction are listed with each entry. In some instances a brief description and location of the property are included. A copy of a partial page from a typical grantee index book is shown in Figure 13.1. A grantor book is identical except that the index is on the name of the grantor rather than the grantee.

The Title Search

As noted, the deed research conducted by surveyors themselves varies widely in different regions of the country. In the public land states, surveyors often rely on reports, public records, the field notes of the original surveyor, and reports prepared by title companies providing title insurance to the lender and/or buyer. The simple fact that a title company is providing such insurance based on its own search of the records does not lessen or eliminate the liability of the surveyor to assemble the chain of title and conduct a deed search. The surveyors in the original 13 colonies (and the lands claimed thereby) often conduct their own deed research as part of the normal standard of care. This normal standard of care includes researching the adjoining properties as well.

If conducting one, the subject deed should be searched back in time until the property lines of the tract involved originated. From the surveyor's viewpoint, the search is to determine intent of the parties at the time of the original survey or, if there was no original survey, the intent of the parties based on the original writings. The search should establish a line of unbroken ownership in the subject property.

Having concluded the search back in time, the reverse process—called a *forward search*—is then conducted.

GRANTEE General Index To Real Estate Conveyances - Forsyth County, N.C.

☞To Locate Names, Open at SURNAME INITIAL TAB and Refer To Buff Sub-Index Sheet For Page Reference

Made By The Cott Index Company, Columbus, Ohio
Sold By Observer Printing House, Charlotte, N.C.

DATE OF INST.	GRANTEES				GRANTOR	KIND OF INSTRUMENT	RECORDED		BRIEF DESCRIPTION, LOCATION, ETC.
	SURNAMES	GIVEN NAMES ABCDEFGH	GIVEN NAMES IJKLMNO	GIVEN NAMES PQRSTUVWXYZ			Book	Page	
1987	Gilder		J.	Roger	James M. & Margret Lipsitt	Deed	974	107	George D. Lester Property
1987	DO		J.	Roger	Larry S. & Judy Smith	Deed	976	426	Block 18, Lot 7-Greenhills
1988	DO	Frank	L.		Mark N. & Sally Johnson	Deed	981	331	Thomas Morrison Tract
1988	DO		J.	R.	Robert L. Martin & Wife Paula	Lease	984	274	Easement
1988	DO	Frank	L.		P. L. Bandcroff	Deed	985	67	Harris #3 Tract
1988	DO	Frank	L.		Kenneth & Mary Spillman	D of T	987	493	Lot 41, Block 3-College Park

FIGURE 13.1 Typical index page for grantees.

The forward search begins with the name of oldest grantee from the search described here. In the subsequent conveyance, this name becomes the grantor. Using the grantor index and starting with this name, title can be traced forward in time to the present. This provides the surveyor with the chain of grantors. By reviewing each conveyance, it can be determined whether any owner in the chain of title has encumbered or impaired title to the land with, for example, easements, other sales, mortgages, or liens. This search also reveals the creation of servient estates (for example, providing access to the real estate across another property), reservations, and exceptions.

This chain is composed of links. A link is a connection or transfer of property between consecutive owners of the property. These links are not always in the form of a deed but can be a will, the records of an intestate estate (an estate left by a deceased without a will), or a court order. In the absence of a will, the actions of the court must be documented. In order to place the various documents in their proper chronological order and context, a brief summary of each may be prepared. See Figure 13.2 for an example of such an information sheet. Surveyors should be particularly concerned with the boundary description in each conveyance. They must look for discrepancies in the current deed and may check the current description against those in prior legal instruments. If plats of survey exist, the deed descriptions should be checked against the plats for inconsistencies.

A postsurvey discovery that the real estate in question lacks legal access or that the title to the property is in ques-

Grantor:

John Smith & Wife Jill

Grantee:

David Doe & Wife Dawn

Instrument Deed
Book 1037 **Page** 401
Date 9/13/90
Acknowledged 9/15/90
Recorded 9/15/90
Warranty Fee Simple
Considerations $ 50,700.00
Stamps $127,000
Liens *None*
Released ---
Restrictions *Deed Book* 1035 *Pg* 207
Acknowledgement O.K.
Execution O.K.

Granting Clause

Smith & Wife--Grant & Convey--Doe & Wife joint tenants/right of survivorship

Description:

Being all of lot 14, Block 9, Section 4
Pine Hills Sub-division

Source of Title Deed Book 1032 **Page** 140

FIGURE 13.2 Information sheet for deed search.

tion is both embarrassing and problematic for the surveyor as well as for the client.

A break in the chain of title occurs when a source reference to a prior conveyance is not found. If this should happen, then a search beyond the record books must be made to determine whether a land title was actually conveyed. Such a transfer can occur by some means such as a will, and therefore no deed would be recorded. This makes the search more difficult and more time consuming.

Wills are often kept by the clerk of the court of the county or city where the subject property is located. For estates settled without wills, one has to resort to the probate records. Sometimes birth and death records can aid in determining time frames to limit searches for wills and the decisions reached in estate settlements.

Check of Adjoining Property

Adjoining deeds are checked using the most recent descriptions. Boundary lines of the subject tract are compared with those of the adjoiners to determine whether any discrepancies exist. If conflicts are revealed, the associated adjoiner's deed might have to be checked back in time to determine the intent of the original parties when the line was created. As with the title search on the subject tract, this check is accomplished using the grantee-grantor index book to trace the adjoiner's description to the point in time when the line in question originated.

When the calls on the same lines in adjoining deeds do not agree, it may be necessary to establish senior rights for the line in question. *Senior rights* are those rights gained by virtue of being the first parcel created out of a tract. The law provides that if a grantor conveys land to a grantee, he or she cannot later convey that same land to someone else. The first deed in such a case would be the senior deed. Therefore, the written intentions of a later deed for property previously conveyed would only convey that portion of property reaching to the land of the senior title holder. While the senior rights may be researched by the surveyor, it is important to remember that senior rights are related to the integrity of the title that a title company is insuring. Thus, when there is a title company insuring the conveyance, the issue may not be "which property is senior?" as much as "what is the title company going to insure?" Typically, a title company will not insure the land in an overlap area regardless of which property is shown senior.

ANALYSIS OF INFORMATION AND PREPARATION OF COMPOSITE MAP

Having either assembled or been provided with the descriptions necessary to perform the survey, the surveyor should determine whether these descriptions do, in fact, cover the proposed development area and that the acreage as called for in the document of conveyance is confirmed by the computed quantity.

It is the surveyor's job to interpret the intent of the description and to place the lines and corners it describes on the ground in accordance with accepted principles of law.

Much emphasis is placed on the intention of the parties at the time a monument or boundary originates, so surveyors must know how to find that intent in a manner that will be upheld in a court of law should their interpretation be questioned. Except in specific instances, intent should be garnered exclusively from the writings—which are considered to represent the intentional acts of the parties. Only when the writings cannot be interpreted without additional evidence or when the description is so ambiguous as to beg explanation, can surveyors seek clarifying evidence from outside the deed.

The acts and intentions of the parties should be considered under the circumstances existing at the time of origination. Thus, one frequent reason for seeking outside evidence is to clarify what those conditions might have been. For example, a deed call "to the right of way line" of a street that has been widened numerous times will require research of additional documents outside the deed itself to determine which right-of-way line was being contemplated by the description.

Once all of the records pertinent to the subject property have been obtained, the work of examining those records for determining boundaries can begin.

The starting point for the resurvey or retracement must be the same point described as such in the record description. In the public land states, this point is typically a section, quarter section, or quarter-quarter section corner, and the primary challenge is to determine where that corner was established originally. The corners determine the lines that enclose the parcel and the aliquot lines. Aliquot lines are the lines used to form equal parts of a section. In the metes-and-bounds states, the intent may be less clear, and the goal is to identify the point *most* closely in agreement with the description as written and the evidence of actual ground possession.

The analysis of the boundary continues using all appropriate information gathered during the research phase. A composite map of the subject tract and adjoining tracts is typically prepared. Figure 13.3 is an example of a composite map. Each description from the various tracts of land is plotted at the same scale and in reference to the particular tract being surveyed, much in the same manner that the parts of a jigsaw puzzle are assembled.

The composite map will include the bearings, distances, and calls for every line and corner represented. The composite map thus becomes the surveyor's guide for determining where evidence of the boundaries might be found during the field survey. It is also helpful in identifying potential conflicts between the subject tract and that of the adjoining tracts.

The surveyor should realize that evidence should be viewed considering the rules of law. Some of these rules of law will be covered in more detail in a subsequent chapter on the legal aspects of surveying. It is, however, necessary to consider them now for understanding of the analysis process.

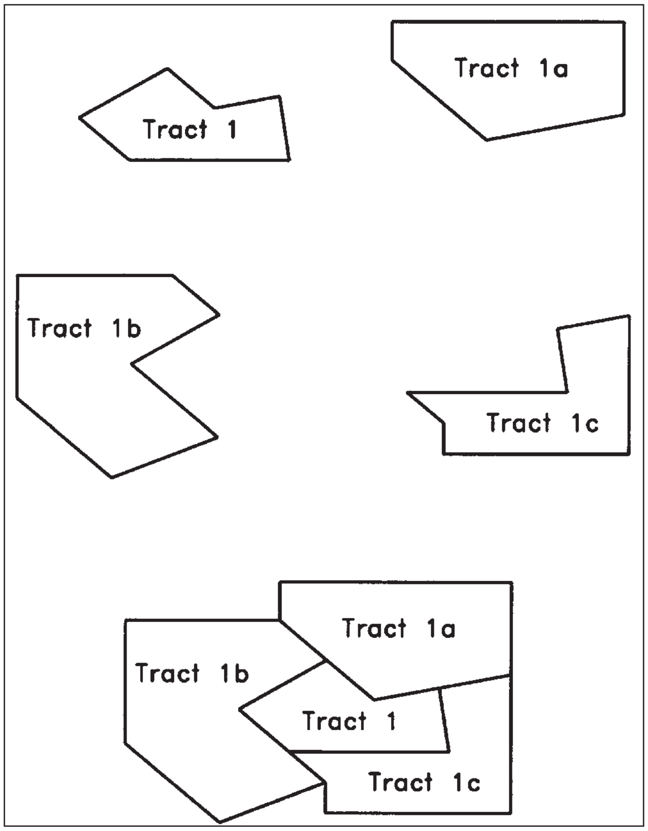

FIGURE 13.3 Composite map.

Monuments

Before surveyors can begin making decisions related to the use and application of existing monumentation in determining the location of lines, they must understand the difference between existing corners, obliterated corners, and lost corners. Existing corners are defined as "those whose position can be identified by verifying the evidence of the monument or its accessories, by reference to the description in the field notes, or located by an acceptable supplemental survey record, some physical evidence, or testimony" (*Manual of Surveying Instructions,* 1973, Tech. Bulletin 6).

An obliterated monument is one where no visible evidence of the work of the original surveyor remains to support the location as an original monument. Its location has, however, been preserved by acts of the landowners or is otherwise recoverable based on other supplemental evidence. The location can also be established from the memory of those who knew of the location of the original monument.

A lost corner is a point of a survey whose position cannot be determined by the evidence. When no traces of original marks are found and no acceptable evidence or testimony is available that supports the location of the corner, it is considered lost. The position of a lost corner can be restored only by reference to other independent corners.

Monuments control in the decision process when they meet the standards stated in the law. The law requires that a specific call must exist in the deed or other instrument for a point to have the standing of a controlling monument. An example of a specific call is as follows: "thence North 35° 15′ West, 1357.8 feet along a fence line." The words "along a fence line" give the fence the standing of monumentation, and the fence takes precedence over the bearing. Monuments not called for in the deed are usually not controlling factors in determination of boundaries in a court of law. The monument must have characteristics that make it identifiable as the original monument. Evidence of the monument's disturbance weaken its standing.

Discrepancies

The surveyor must check for consistency of identifying calls for monuments by adjoining documents with those of the subject property. Any differences should be noted and reconciled if possible.

Discrepancies in metes-and-bounds descriptions are often the result of variation in magnetic north between the time the legal description was constructed and the present reference to north, as well as the instruments used to perform the survey. Variation in distances can also exist. Both human error and improvements in technology are factors in discrepancies between calls in different documents.

Frequently the surveyor must search the records for a longer time than required for title purposes. There are two reasons for this extended search. As previously discussed, when senior rights are involved in the determination of ownership, such a search may be mandated. The second situation is required because bearings are often copied from older deeds. The origin of the bearing would be the date of the survey that produced the bearing. The date of the origin of the bearing must be known so corrections for magnetic declination can be properly made. This is necessary in the proper preparation of the composite map. Reference to direction in different documents having various dates can be adjusted to a common north system of reference. This common reference could be true north, State Plane Coordinate Grid North, or some other local system that might be prescribed.

Differences in distances can result from a failure to convert units used in original surveys to those of the adjoining property or those in use at present. Reconstructing an old survey is not a simple matter. The surveyor must be familiar with the units of measurement used at the time the original survey was made. Often these measurements had more than one interpretation.

Early land grants were often described using differing lengths of chains and varying sizes of acres. The best example of this is given by the variation in the acre in different parts of England. In Devonshire and Somersetshire, the acre was 160 perches of 15 feet, or 36,000 square feet. In Cornwall, the perches were 18 feet and yielded 51,840 square feet. In Lancashire, the perches were 21 feet and the acre was 70,560 square feet. When the early settlers of this country began to survey the land, they often used the measure with which they were familiar.

Courts throughout the United States, particularly in the western states, have found that many of the original government surveys of parts of the public lands were imprecise. The reasons for these inaccuracies included low land value, difficulties encountered during the surveys, and, in some cases, outright fraud. This phenomenon is also true for those early surveys of the original grants in this country.

Preparing for the Fieldwork

Typically, a comprehensive map (see Figure 13.4) is prepared for use by the survey crew in conducting the fieldwork on the survey. The map should include information on those points and lines mentioned in the various deeds and documents. Positions of monuments called for in adjoiners' deeds should be indicated and labeled. Horizontal traverse control to be used for survey is shown and identified.

Tax parcel numbers, names of adjoining owners, deed book, page numbers, and acreage are given for each of the adjoining tracts. Assembling a file for the survey project in an orderly manner such as that outlined as follows provides a valuable reference for the field crew and for future reference.

1. A tax map with subject tract outlined in color and a tabulation of ownership information derived from the local tax or real estate assessment office.
2. The chain of title and other research notes properly arranged in chronological order.
3. All deed descriptions with tax assessment parcel numbers and deed book and page numbers identified.
4. Any other miscellaneous plats, aerial photographs, or related information.
5. Tax maps alone should not be used for boundary determination.

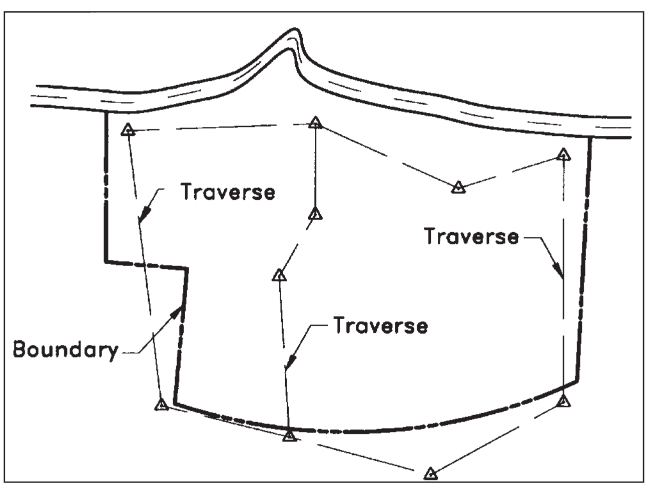

Figure 13.4 Field map.

APPLICATION OF INFORMATION TO THE BOUNDARY SURVEY

It is important to realize that office work and fieldwork progress jointly. The two functions are interdependent. Office work requires continual input of field data to move forward efficiently and effectively. Continued fieldwork requires office computations and analysis of data previously supplied.

Standards

Boundary surveys for land development differ from the typical rural or farm boundary survey. In addition to gathering evidence for property line location and for use by the title company in evaluating potential title problems, these surveys require the compilation of features that affect the later development.

For a description of what must typically be located in the field and shown on such a survey, refer to the Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys in the Appendix G as well as specific state standards.

In addition, most states have a set of standards adopted by their boards of registration. These standards vary in detail significantly from state to state, but all outline minimum requirements for the practice of surveying in each state, and registrants must meet these standards in addition to any other site- or client-specific requirements.

Fieldwork

The field phase begins with reconnaissance to locate corners or other calls referred to in descriptions and pertinent to the survey. The reconnaissance also serves as a basis for planning the subsequent fieldwork. When appropriate, it provides an opportunity to notify adjoining landowners of the impending survey. This notification might also be done in a more formal manner. Some states require written notice to adjoiners before the fieldwork begins. The field survey will proceed more smoothly if the cooperation of adjoining landowners can be secured.

The Traverse Survey

Having established the standards under which the work will be undertaken, a random traverse of the subject property is typically run. The traverse may be conducted using conventional equipment and procedures, such as measuring angles and distances with a total station or theodolite and an electronic distance-measuring (EDM) device, or the surveyor may employ the use of global positioning system (GPS) receivers to establish locations using satellites. Frequently a combination of procedures and equipment is used. Available personnel, terrain, improvements, vegetation, and traffic often dictate the most logical equipment and procedures to employ.

No matter what procedures and equipment are used, the lines and points on the traverse should be located on the subject property when at all possible to prevent damage to trees and shrubs belonging to adjoining owners. Stations on the survey should be placed at the most advantageous locations and frequencies, considering they will subsequently be used to locate features on the property and possibly for other functions later in the development process. These uses include topographical surveys, construction stakeout work, and control surveys for the development. If points are destroyed, the configuration of the initial traverse should allow for easy replacement.

The traverse control points serve as the basis for locating visible, found, or described corners, fences, tree lines, and other features relevant to the title, lines, and corners in addition to those improvements called for in the state or ALTA/ACSM standards or as may be required by the client.

Cross-ties between nonadjacent points of the traverse should be made as frequently as is practical. This affords checks on the survey work and allows for better survey adjustment of final results. These cross-ties also provide additional stations for control and stakeout in later stages of development. Survey markers set on this traverse, such as rebar, pipes, or concrete monuments, should be of a length and diameter to be secure after installation or as required by state minimum standards. Alternative objects such as “PK” nails or scribe marks can be used when they are more suitable for the conditions.

All traverse stations should be referenced for ease of future recovery. A minimum of three references is desirable. The references should be accurately described and recorded in the field notes. See the illustration in Figure 13.5 for an example.

Field crews must be sure that the information to be located in relation to the boundary traverse is properly tied to the survey traverse line using methods that afford redundancy in measurement to better ensure the integrity of the data. This is particularly important when locating markers and monuments, which are integral to the resolution of the boundary. See Figure 13.6 for an example of points to be tied to the traverse.

Blunders must be eliminated by a redundancy of measurements. Following correct procedures to prevent human errors such as misreading equipment and errors in note keeping is an absolute necessity. A few simple additional control measurements allow for field determinations and

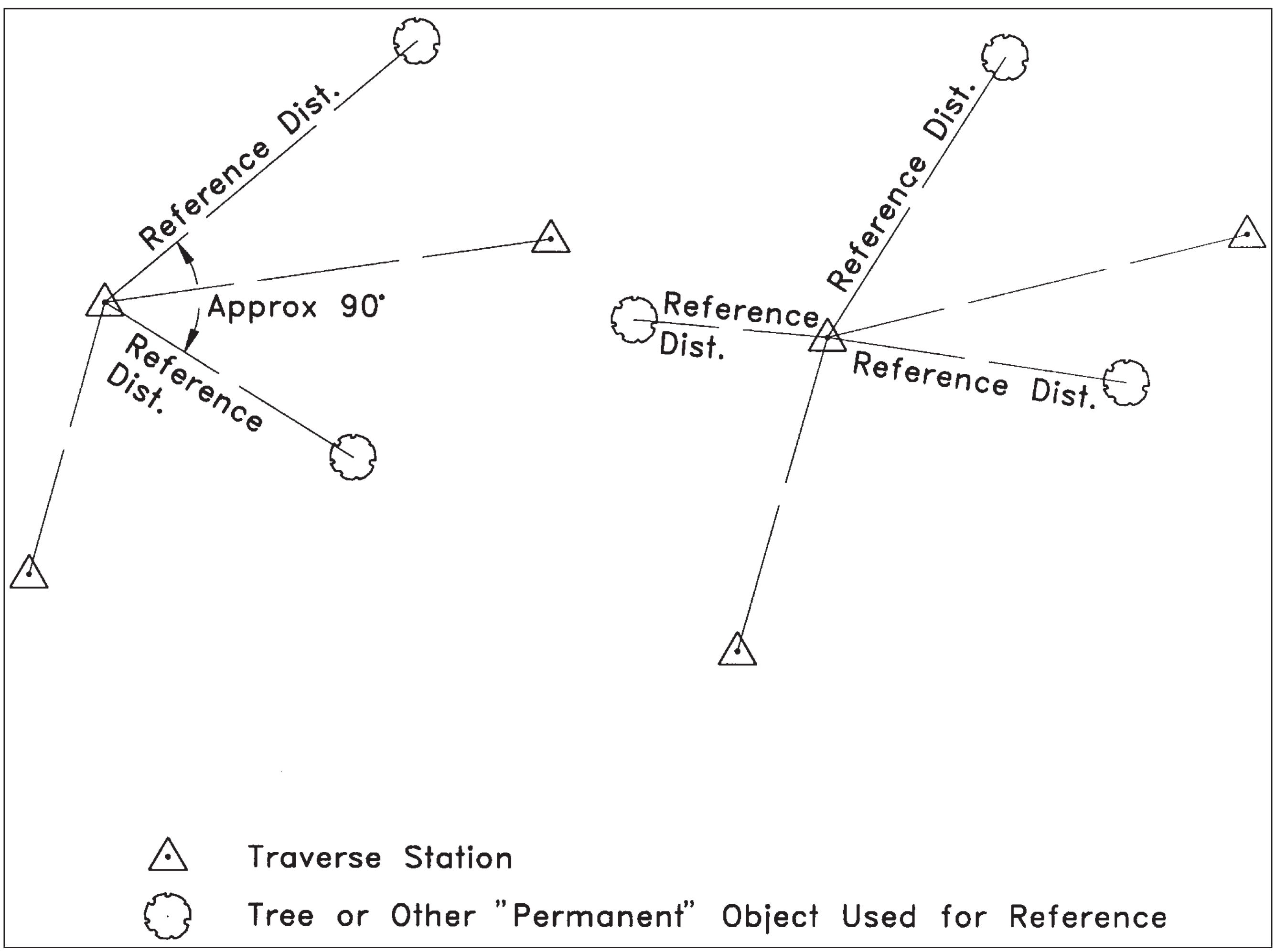

FIGURE 13.5 Methods to reference traverse stations (transverse ties).

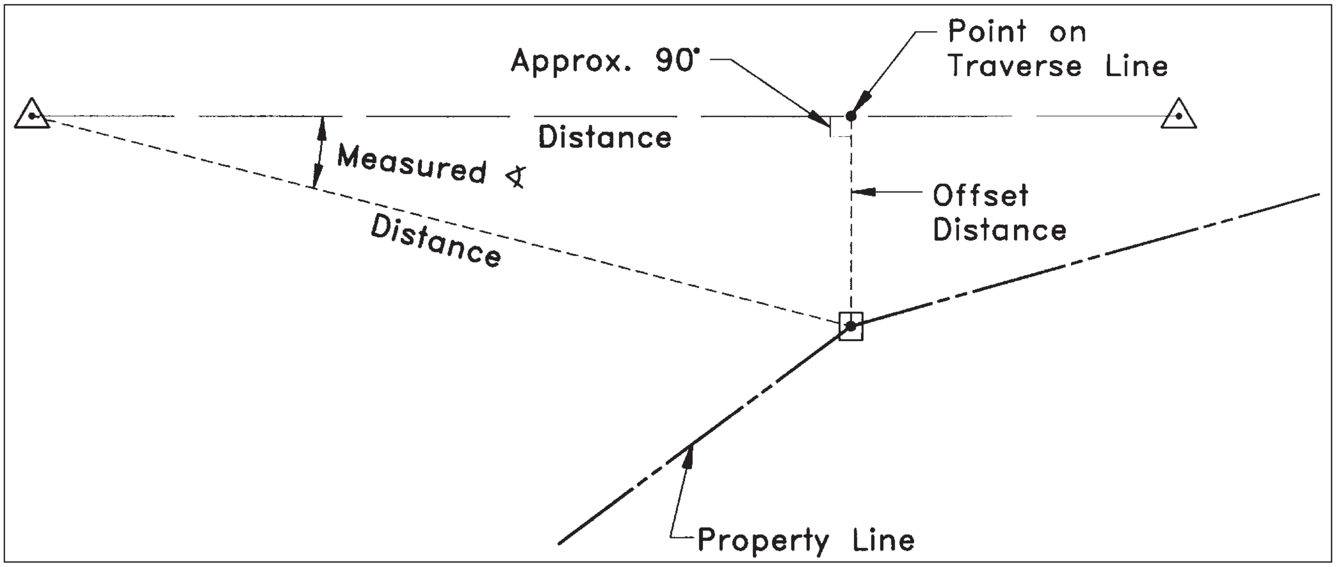

FIGURE 13.6 A boundary point is tied to the traverse using a minimum of two references. Shown here is (*a*) a measured angle and distance directly to the point and (*b*) measured distance to POL (point on line) and offset distance to the point.

an immediate rectification of such errors where required. Extra trips to the field can be avoided by using a pocket calculator for checking measured data against a mathematical fit.

Locating Features and Improvements

The lines of the boundary traverse should follow the record lines when possible, since the traverse serves as the basis for locating evidence that determines the position of the actual property line.

Found iron pipes, concrete markers, stakes, and other objects used to mark corners and points on line are evidence and must be located. The locations of tree lines, old fence lines, walls, ditches, and other features on or near the division lines must be determined and described in detail, including the material from which objects are made and the condition of the objects. Photographs of the evidence for future reference are helpful. Such photographs can provide excellent supportive evidence should the survey result in litigation. Points found during the survey and called for in the deed should be used as traverse stations when they are accessible.

Existing streets may have an impact on the boundary line determination and later development. The locations of pavement, right-of-way lines, and centerlines should be recorded in the field notes. When no pavement exists, the traveled way should be located. Access roads on or across property, whether in use or not, should be located and shown. Such roads might be used for access to surrounding property and as such might be included in an easement. Cuts or embankments, tree lines, or fencerows, which might indicate long-abandoned roads, should be located and shown.

Drainage ditches, streams, creeks, and rivers must be recorded in the traverse survey notes. Details about these features are most important in the land development process. Locate these features if they are mentioned as a boundary or if they cross a boundary line. Information on the size and condition of waterways should be included in the field notes.

A complete explanation of the conduct of the fieldwork is beyond the scope of this book. Surveyors unfamiliar with generally accepted standards and procedures should consult appropriate sources of information and their peers for assistance.

Easements

Many land and title features may be located within easements. In addition, easements needed to install or maintain the infrastructure of the land development must be established. These include easements for streets, wells, drainfields, stormwater runoff, storm and sanitary sewers, gas lines, and power lines. Because of their importance, the nature and location of easements that already exist and those that are to be created must be carefully considered. Often, proposed easements will connect to existing easements.

A simple general definition of an easement is a nonpossessory interest held by one person in land of another. The person holding that interest is accorded partial use of the burdened estate for a specific purpose. An easement restricts but does not abridge the rights of the burdened estate fee owner to the use and enjoyment of his or her land.

Two types of easements, namely express and implied, can lead to land disputes. The law provides for express easements. The law also recognizes that easements may exist or be created that are not express. These are implied and prescriptive easements.

Easements fall into three broad classifications: surface, subsurface, and aerial.

It is important that the surveyor identify whether any easements exist at the time the boundary survey is being conducted, since they may interfere with later development plans. This is why locating existing and potential easements is such an important part of any survey. Should any possibilities of easements exist, they must be reported to the client at the time of the boundary survey. It is not the surveyor's responsibility to determine whether an easement has been created in fact, but instead it is the surveyor's responsibility to report its possibility.

Many times old logging roads or field roads exist on a property to be developed. These can usually be easily seen on an aerial photograph or visually located by ground survey. This type of road could be evidence of an existing easement created by prior use or by necessity. If by chance the adjoining land became landlocked because of the closure of such a road, an easement by necessity could be required across the burdened property.

Some states have statutes to provide for easements of various widths for ingress and egress to public highways over intervening lands. There are many purposes for granting these easements. Some common examples are cultivation, cutting and removing of timber, mining operations of various types, and manufacturing plants.

Locations of future easements that are required for development should be considered while the boundary survey is in progress if the development plans are far enough along to give such consideration. This can be done by referencing service lines of different types that adjoin or cross the subject property. It is the surveyor's duty to report to the client all possibilities of easements found. In accomplishing this, the surveyor must apply that degree of skill usually exercised by a person of ordinary prudence engaged in the same work.

Grave Sites

It is critically important to locate any evidence of the existence of grave sites. The ALTA/ACSM Minimum Standards emphasize this importance. In some jurisdictions, grave sites are granted protection against disturbance by law even if no easements or other records concerning these sites exist. Aerial photos are useful in location of deserted graves and cemeteries. Burial plots are often near groves of trees or the tops of knolls. Time spent locating these sites on a photograph and a field trip to examine these areas are necessary to avoid problems that occur when a grave site is overlooked. During this closer inspection the surveyor should look for grave markers (both head and foot markers) and depressions in the ground.

Evidence of Possession

The surveyor should make careful notes of all visible evidence of possession or occupation such as the cutting of timber, farming, and construction. Any evidence that could be construed as possession of the land must be investigated and identified. The ALTA/ACSM Minimum Standards outline the surveyor's responsibility in this regard in careful detail. Possession can ripen into a fee right that could destroy prior title rights. When land development is pending, failure to discover claims related to such possession can lead to long and costly delays and even work stoppage as the project progresses. The possibility also exists that injunctions over such matters might stop future land sales.

Office Work and Computations

Contact between the party chief in the field and the office surveyor (compiler and computer) should be regularly maintained. It is necessary that they work as a team. They must develop a joint feeling of accomplishment in a job well done.

Once the data-gathering phase of fieldwork is completed, the field notes are turned over to the person assigned to compiling and computing the information for the project. This is the time for the party chief and the person in charge of office computations for the project to coordinate their efforts. The party chief can relay any additional information known by him or her to the person compiling the data. Such information might include a variety of observations of conditions on the ground that, for whatever reason, did not find their way into the field notes.

As all this information is compiled into a presentable format, the surveyor can begin to make a determination of boundary locations. He or she should start by checking the field data. Aerial photographs may be used for comparison of data if possible. Field information on lines and points found can be compared with lines and points called for in the record documents. The composite map previously referred to is most helpful when the field data is added to it. The map becomes the main source of comparison of field and record data.

Before the survey data can be plotted, the field notes must be reduced. Averages must be determined when multiple angles and distances were measured.

In confirming the mathematical integrity, or *closure,* of a traverse, angles are checked for error first. Most survey software programs today give the error of closure of a traverse loop, and the specifics of the angular error and distance error for evaluation of whether the closure is within the allowable tolerances.

After determining that the result of the angular error lies within the allowable limits, as documented in the specifications, then the angles are adjusted. Using these adjusted angles, a closure can be calculated for the traverse to determine the linear error. If this precision is within prescribed limits, which may also have been set by specifications, then adjustments can be made for the balance of the error. Should either angles or distances lie beyond the limits allowed, they must be remeasured. Office computations can be made to determine which measurements might be in error. The field crew must return to the field to remeasure suspect angles or distances.

The use and application of *positional tolerance* or *positional uncertainty* are becoming commonplace in federal and state standards, and they now also appear in the ALTA/ACSM Minimum Standards. This concept involves the quantification of probable errors in individual measurements and the computation of the resulting potential error in the locations of the points on the survey. Such a standard typically does not dictate procedures or equipment, but rather allows the surveyor latitude in applying proper procedures and employing equipment and personnel in a manner that he or she sees fit as long as he or she can ensure that the allowable tolerances are not exceeded.

Where no specifications are otherwise required by contract or state laws, the Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys can serve as a guide for allowable errors in both angles and distances, although, as mentioned earlier, these standards will most likely be a part of the contractual requirements. The surveyor should keep in mind that he or she must strive for higher standards than the minimum. Some work requires much higher precision, and the surveyor should be acquainted with the local requirements of precision for development.

Once the integrity of the control survey points has been ensured, the coordinate values of all points included in or located from the traverse are computed. This includes fences, pipes, and monuments in addition to all other points of reference. All of these points are plotted in their respective positions relative to each other.

This location data is used as the basis for the evaluation of the field evidence in conjunction with analysis of the evidence contained in the various record documents and deeds. Using accepted principles of law, the various pieces of evidence are given their appropriate weight and the locations of the missing corners are computed.

The relationships of these points to their nearest traverse stations are determined, allowing the field crew to make an efficient and more complete field search for these points.

The person assigned to making boundary determinations should walk all lines of the survey searching for points called for but not found and looking for fences, utility lines, encroachments, roads, streams, or other items inadvertently omitted from the survey. Before reporting a monument as destroyed, it must be ascertained that destruction has occurred. This is as important as the location of objects that were found. A buried monument or a bound called for but slightly out of place and found too late can be a source of serious future problems. This trip facilitates decisions related to the final boundary placement. The surveyor must be sure that nothing affecting the location of the boundary is overlooked.

Boundary Determination

The surveyor has no legal power to establish subsequent boundaries after the original survey. Their function is one of identifying the most conclusive evidence about the existing limits, precise location (based on the description), and ownership of real property. To carry out this task there are two principles that guide the surveyor. The surveyor must follow both of them as the specific condition dictates.

The first principle is that the intentions of the parties at the time the boundaries and corners originated are to be construed exclusively from the description itself, unless extrinsic evidence is required to do so. The boundary lines and corners are then established accordingly. Many times the task of identifying intent necessarily includes analysis of field conditions to assist in understanding the initial intent. Intent is considered a legal concept for boundary retracement and determination.

As time progresses, the evidence of intent becomes less clear, and incomplete evidence can lead to incorrect conclusions. This prompted the need in law for the development of a second principle. This basic rule is that lacking clear intent in the writings, the long-standing acceptance of a boundary location may be considered evidence of the originally intended location.

The application of this rule is probably more important where the land being surveyed is in the process of development. Much consideration should be given to the claims of adjoining landowners. If minor differences can be reconciled by agreement with adjoiners, this is usually the most appropriate method of settling such disputes. If an adjoiner has been claiming a boundary and has possession of the claim, the fact that litigation is time consuming and costly must be given weighted consideration.

In surveys where relocated corners do not agree with all calls of original documents or notes attention must be given to the rules of construction for ambiguous descriptions. These rules simply set the priority for considering physical evidence. That order is as follows: (1) natural monuments, (2) artificial monuments, (3) calls for adjoiners, (4) courses and distances, and (5) acreage. When the inconsistency is between course and distance, the distance is generally considered more reliable, not necessarily more legal, although this depends on the state in which the property lies. This subject is discussed in more detail in the section “Legal Considerations in Boundary Determination.” The surveyor must understand that these rules of construction are subject to change if they result in absurd conclusions. The choice for construction is the one that brings the most harmony with the deed.

LEGAL CONSIDERATIONS IN BOUNDARY DETERMINATION

Thomas M. Cooley, chief justice of the Michigan Supreme Court in the 1880s, was the author of the address titled “The Judicial Functions of Surveyors.” This address covered the role of surveyors when they are performing relocation surveys of old boundaries. The concluding statement from this address was: “Surveyors are not and cannot be judicial officers, but in many cases they act in a quasi-judicial capacity with the acquiescence of parties concerned; and it is important for them to know by what rules they are to be guided in the discharge of their judicial functions.”[1]

All deeds, wills, agreements, and evidence must be considered in making the final determination of a boundary

[1] *Diehl v. Zanger,* 39 Mich. 601,605 (1878).

location. Surveyors gather and analyze the evidence to support claims concerning the true location of corners and lines. The determination must be made considering the intentions of the parties at the time the boundary was first established. The laws governing surveying and real property also play an important part in the decision process and in the weighing of the evidence to support claims. Final boundary determinations rest with the courts, but fortunately, as stated earlier, most boundary problems can be resolved with confidence by competent surveyors.

Conflicting Title Elements

In making decisions based on discovered evidence, the surveyor must be familiar with the order of importance of conflicting title elements. These elements were mentioned earlier and are discussed subsequently. The surveyor must be familiar with cases enabling conclusions to be drawn based on precedence set down by the courts in similar situations.

Possession

The first of these elements of importance is the right of possession. These are the rights not stated in writing but, as pointed out earlier, can become rights in fee. This fact is cause to give first and highest consideration to these unwritten yet visible claims to land ownership. The consideration of unwritten rights often involves adverse possession, although there are a number of other types of unwritten rights such as acquiescence, estoppel, and oral agreement. Such possession is a matter often determined initially by a land survey and ultimately, in most states, by a court of law; the surveyor cannot make a determination of the legality of the possession. The more evidence the surveyor gathers, the better able he or she is to inform the client as to the potential of an adverse claim.

Adverse possession is a means of gaining ownership of land based on possession. This form of obtaining ownership is one that can cause many problems for the land developer and the surveyor.

This doctrine began in feudal England with statutes of limitation. The limitation under English statutes was set at 20 years. The time was referenced to some royal event such as a coronation or death of a king. The feudal concept of ownership was based on possession.

The modern principle of specifying a uniform number of years as the limitations period for real property actions began during the reign of Henry VIII. Early American colonies and several states today have continued a limitations period of 20 years as it was set in the 1623 Statute of James I. Under this early statute, if a freeholder was dispossessed he had the chance to regain possession and claim to the estate of freehold.

This is accomplished today by bringing an action similar to the ancient writ designed to recover real property interests. The dispossessed party must seek a writ of right or possession before the statute of limitations expires. Failure to comply with this requirement may result in the rights of the party that is dispossessed becoming absolute. The modern principle of adverse possession differs because the record owner does not lose title or ownership when the adverse possession begins, but rather after the statute of limitations has run.

Gaining of title by adverse possession is dependent on a variety of factors in addition to meeting the statute of limitations. If those requirements are met, the record title owner may lose that title through later judicial processes and the person with adverse possession rights might become owner of the property.

The claimant's possession generally must be open and notorious, continuous, hostile, actual, visible, exclusive, and under a claim of title. The exact combination of requirements and the length of the statute of limitations vary from state to state. In any case, however, the statutory period necessary to defeat title and satisfy the required statute of limitations must be met (Brown, Robillard, and Wilson, 2006, sec. 13–38).

The elements of adverse possession are required because the record owner must have actual knowledge of the adverse claim against his or her holdings. The terms *open, notorious, actual,* and *visible* all raise the presumption at law of notice. The true owner being intentionally infringed upon is essentially given this notice by virtue of the claimant meeting these requirements.

Hostile possession is often misunderstood. A good example of its meaning can be explained by resorting to case law. The majority rule is that possession based on a survey mistake is sufficiently hostile. This is true as long as the person in possession is claiming the property as his or her own (Powell, 1987, ¶1013[2][f][i]).

The requirement of continuous possession means that the true record owner of the land has had suitable cause (right to act) and time to bring legal action against the adverse claimant during the entire time of possession.

The requirement that the possession be exclusive might be characterized by a situation whereby anyone other than the adverse claimant must receive his or her permission to enter on or use the land being possessed.

Senior Rights

The next element in order of importance for determining ownership is called *senior rights.* A brief discussion of senior rights was included earlier in this chapter. Senior rights have been stated as the rule of "first in deed and last in will" (Brown, Robillard and Wilson, 2003, sec. 11.6). Put another way, this statement simply means that one's interest in land can be transferred to another party or parties only once. This prevents the same interest from being sold later at a date to another party or parties.

Written Intentions of the Parties

After consideration of the preceding elements, the written intentions of the parties are the paramount consideration.

These intentions are those expressed by the parties to a conveyance and put in writing in the document that brings about that conveyance. The written intentions of the description are used to consider the importance of the remaining conflicting title elements. The strongest expression of intent is a call for a survey.

Calls for Monuments

Monuments are the next element to consider when a situation of conflicting elements arises. Natural monuments usually take precedence over artificial monuments. In some instances, artificial monuments can become so well identified that they obtain equal standing with the natural monuments. When an object built by humans becomes generally well known and recognized and is considered permanent, it may attain the characteristics of a natural monument

Monuments of record (sometimes referred to as calls for adjoiners) are often considered a third type of monument. Calls for record monuments become relevant when other calls result in gaps or overlaps with adjoiners. Record monuments most often gain importance in situations involving senior rights, although a call for an adjoiner does not in and of itself establish senior rights.

Distance, Direction, Area, and Coordinates

After consideration of the monuments, elements such as distance, bearings, or directions called for in the description are next in importance, respectively. Area does not have a high priority in the conflicting elements except in cases of wills. The intent in wills and in some descriptions is often expressed specifically by a certain number of acres, and in those cases, area receives first consideration.

Coordinates are given little consideration. They are generated from information already mentioned. Therefore, they are subject to mistakes in computation. Parties to a conveyance rarely understand the relationship of coordinates to a field location, so they cannot represent intentions of these parties.

There are other legal possibilities that might affect the location of property lines. These include boundaries by agreement, acquiescence, and estoppel.

Boundaries by Agreement

Confirming that a boundary has been established by agreement is dependent on finding a mutual agreement between landowners as to where the common boundary is located. Courts often require that certain factors be present before boundaries can be established based on such agreements. Boundary agreements must involve lines or corners that are uncertain or disputed. These agreements must set out a specific line as the boundary. They must be executed by acts of the parties occupying adjoining land, and the agreement must include land to the agreed line. The final requirement is that the agreement be recognized for a considerable time. This period is often equal to that required for adverse possession.

Boundaries by Acquiescence

Acquiescence is similar to boundaries by agreement. This type of ownership is unique, however, because it does not require proof that the boundary location resulted from an agreement. For this doctrine to be enforceable, occupation must be visible up to a definite marked line. Generally, a long period of time must elapse before acquiescence exists, although one theory of acquiescence is that it is based on a prior agreement.

Boundaries by Estoppel

Boundaries by estoppel develop when the true owner knowingly misrepresents his or her boundary and causes a neighbor to rely on the misrepresentation, thereby incurring detrimental cost. In such cases, the boundary becomes that as represented. Estoppel is defined as "a man's own act or acceptance stops or closes his mouth to allege or plead the truth."[2] The concept of estoppel works to bar, stop, impede, prevent, or preclude denial of a certain fact as illustrated by the following example. A property owner who knows that an adjoiner is making improvements along a line, which they have incorrectly believed to be the actual boundary line, may later be estopped from claiming a true line running through the improvements.

Party Walls and Line Fences

Line fences are special cases when they divide properties. Known in law as division or partition fences, they are covered by statutes in all but six states. Such a fence is built on an equal amount of land of each of the adjoining owners. Fences built entirely on the land of one party are not division fences. In these cases, the boundary lines prove the fence location. Fences not called for in the description of lines when the lines originated do not prove the lines. A fence can become a line fence by consent of the owner of the land on which the fence was built.

Land development can also involve boundaries established by party walls. Party walls are located similarly to division fences. Party walls are usually built after formal agreement of the concerned owners. Only a few states and the District of Columbia allow the building of such walls without agreement of adjoiners.[3]

Evidence

It is evident that surveyors must consider any factors that might impact future development. Evidence of construction on the land that might be grounds for liens must be reported. Surveyors must also determine from local authorities whether there is any proposed construction around the subject tract. Such construction might cause changes in streets, sidewalks, water, sewer, gas, or other service lines, which could have an impact on the property detrimental to the proposed development.

[2] *Caulfield v. Noonan,* 229 Iowa 955, 295 N.W. 466, 471.

[3] See, e.g., D.C. Code Ann. §§ 1-625 to 1-626 (1981).

In addition to this basic knowledge of law, surveyors must be familiar with state statutes and local ordinances and have a working knowledge of case law related to real property. Those cases related particularly to land development should be checked when a situation of conflict over a boundary develops.

Laws form the basis of land ownership. Proof of the limits of this ownership requires gathering evidence by surveying the boundary. Surveyors should remember that for each law there are many exceptions to that law. Each land survey is unique and different. This is because the physical characteristics of the land vary and the circumstances surrounding the conveyance govern the interpretation of the intentions of the parties.

The deeds located in the record search become the basis for locating and establishing boundaries. They are used to identity the true location of monuments and courses, as originally run, on the ground. This holds even if the measurements by the original surveyor were not precise.

All of this relates to what is called the rules of evidence. The definition of the law of evidence is stated as "the aggregate of rules and principles regulating the burden of proof, admissibility, relevancy, and weight and sufficiency of evidence in legal proceedings" (Black, 1990, s.v. evidence, law of). Evidence may be defined as "Any species of proof or probative matter, legally presented at the trial of an issue, by the acts of the parties and through the medium of witnesses, records, documents, exhibits, concrete objects, etc., for the purpose of inducing belief in the minds of the court or jury as to their contention" (Black, 1990, s.v. evidence). Evidence is not proof but the consideration of it, and the deduction reached from it produces confirmation of what will prevail. Not all evidence carries the same weight in establishing proof.

Indispensable evidence, as the name implies, is that evidence absolutely necessary to prove a particular fact. In the case of land boundaries based on adverse possession, for example, the evidence must establish the fact of that possession, such as enclosure. The surveyor would therefore locate fences, which would constitute indispensable evidence of such enclosure.

Evidence that cannot be disputed is called *conclusive*. The clear contents of a written instrument such as a deed cannot be changed by the oral testimony. Therefore, documents that are a part of a conveyance must be considered in high regard when trying to prove the location of a boundary.

Prima facie evidence is that which will stand as correct until it is rebutted by other evidence. A probated will granting a party ownership to a tract of land is prima facie evidence of that ownership. Proof of the rebuttal of the will would be necessary to contradict such evidence.

Other classes of evidence consist of primary evidence, secondary evidence, direct evidence, indirect evidence, partial evidence, and extrinsic evidence. *Primary evidence* is original or firsthand evidence. It is that evidence which is given priority for ascertaining the truth. A copy of a document is *secondary evidence* because it is considered inferior to the original document.

Direct evidence supports the existence of a fact without depending on proof of other facts. The testimony of an eyewitness to an event is considered direct evidence.

Indirect evidence, on the other hand, requires proof of a fact by proof of another. This evidence is also called *circumstantial evidence*. Evidence used to establish a detached fact is *partial evidence*. This type of evidence is subject to being rejected unless connected to the fact in dispute by proof of other facts.

Extrinsic evidence is that not contained in the body of a document for agreements or contracts. Such evidence is primarily for explanation of references in the written documents. This evidence can be used to clarify meanings of terms that vary within local context.

Surveyors must understand the types of evidence and realize that the law of evidence is not exact but relative. The rules referred to in the definition of the law of evidence can be found in the statute law of the state where the subject property exists. These rules deal with judicial notice, presumptions, and burden of proof—the relevancy, competency, and admissibility of evidence. Other considerations in the rules of evidence include real and demonstrative evidence. Documentary evidence, secondary evidence, and parol evidence are also included. In addition, expert evidence, opinion evidence, and hearsay evidence are discussed in the rules. Topics such as declarations and admissions, weight and sufficiency, and questions of law and fact are dealt with in the same chapter of the statute law.

The understanding of evidence is critical to surveyors involved in land development, since determinations of the location of property lines and corners are often immediately relied on as a basis for work to progress. Often, much or all of the development has been carried to completion before legal problems manifest themselves. Should the land under development become involved in litigation, the surveyor's interpretations will be admitted or rejected in court depending on his or her adherence to the rules governing the law of evidence.

It has been said that "everyone is presumed to know the law, and the surveyor is no exception. This is an irrebuttable presumption that may not be overcome by contrary evidence. If the surveyor agrees to monument a certain written conveyance on the ground, he or she also agrees to locate the conveyance in accordance with the laws regulating the interpretations of written conveyances" (Brown, Robillard, and Wilson, 2006, sec. 2–26).

Basic Rules for Guidance in Boundary Location

Many rules of case law are available to guide surveyors in making determinations concerning boundary locations. These rules are too numerous to include a complete list. They are being constantly added to and amended with each court opinion that is handed down. Some case law included here will make surveyors aware of those that have an application that is more general. Those covering situations that are more specific require research in law libraries. It should be emphasized again that rules of law are often overturned. In addition, exceptions to the rules are commonplace. Rules are therefore only a guide in the decision process. The courts make the final determinations should boundaries fall into dispute. Following are a few of the primary rules established by case law:

Rule 1. In ascertaining boundaries from title papers, he who has the oldest title is entitled to take his courses and distances, go where they may.

Rule 2. Written descriptions of property are to be interpreted in the light of the facts known to and in the minds of the parties at the time. They should be construed with reference to any plats, facts, and monuments on the ground and referred to in the instrument.

Rule 3. Where the description of the boundaries in a deed is indefinite or uncertain, the construction given by the parties, and manifested by their acts on the ground, is considered the true one unless the contrary is clearly shown.

Rule 4. Every call in the description of the premises in a deed must be answered if it can be done, and none is to be rejected if all the parts can stand consistently together.

Rule 5. The certain description must prevail over the uncertain, in absence of controlling circumstances.

Rule 6. Where the boundaries mentioned are inconsistent with each other, those are to be retained which best subserve the prevailing intention manifested on the face of the deed.

Rule 7. When one part of the description in a deed is proved false, and by rejecting that part, a perfect description remains, such a false part should be rejected and the deed held good.

Rule 8. Where land is described as running a certain distance by measure to a known line, that line will control the measure and determine the extent of the grant.

Rule 9. Where a patent calls for unmarked lines of surrounding surveys, the position of which can be accurately ascertained, and there is no evidence as to how the survey was actually made, such unmarked lines will prevail over courses and distances, in case of a conflict. This rule does not hold if the line is obscure, not definitely fixed, marked, or known, and therefore likely to be looked upon by the parties as less certain than the measure given.

Rule 10. Where the description in a deed calls for land "owned and occupied," the actual line of occupation is a material call to be considered in locating the lines of the land bounded therein.

Rule 11. The use of the term "about" indicates that exact precision is not intended, rather where nothing more certain can be found to control the course and distance. Subsequently, the grantee is limited to the exact course and distance given.

Rule 12. Where lines are laid down on a map or plan, and are referred to in a conveyance of land, the courses, distances, and other particulars appearing on such plan are to be as much considered the true description of the land conveyed as they would if expressly recited in the deed.

Rule 13. In construing the description in a deed which bounds the land conveyed upon a street, river, or other monument having width, courts incline strongly to such an interpretation of the language as will carry the fee of the land to the centerline of such monument, rather than to its edge only.

Rule 14. Where a survey is referred to in a deed for greater certainty, it legally forms a part of it, and both should be construed together.

Rule 15. Extrinsic evidence is admissible only when required to explain the conditions existing as of the date of a deed or to resolve an extrinsic ambiguity in the deed.

Rule 16. The mention of quantity of acres after a definite description by metes and bounds, or by the aliquot part of the section, is a matter of description only, and quantity being the least certain, does not control.

Rule 17. Where boundaries are doubtful, then quantity (area) may become a controlling consideration.

Informing the Client

All interested parties should be apprised of the results of the survey by virtue of a plat or map of the survey and an accompanying written report. All facts affecting the boundary and future development of the land should be included, along with notes of all variations from the descriptions found as a result of the survey. The report should address gores, gaps, and overlaps if any exist. Issues of encroachments, easements, rights-of-way, and known violations of any restrictions or regulations should be addressed as well. In general, consider in this report anything affecting property location that might affect the future development.

Preparation of the Final Map and Description

A final plat or map should always be prepared. Many states' regulations and minimum standards require such a document. This plat provides a means of formalizing the determinations made from the survey. It should be prepared while the work is still fresh in the minds of those completing the survey and computations. If this work is delayed, you may omit information that would immediately come to mind if the work had just been completed. Eventually your client, his or her attorney, his or her lender, or a fellow surveyor will require information from the survey.

It is good policy for the person preparing descriptions to sign them. Do not sign descriptions drawn from information that was not a result of a survey made by the signer unless the source of the information used in preparing the description is clearly identified. Reference descriptions to the map used in their preparation. Any communication with the client should be in writing.

A sample final boundary map is included (see Figure 13.7) to provide readers with an example of a boundary survey where land development will follow.

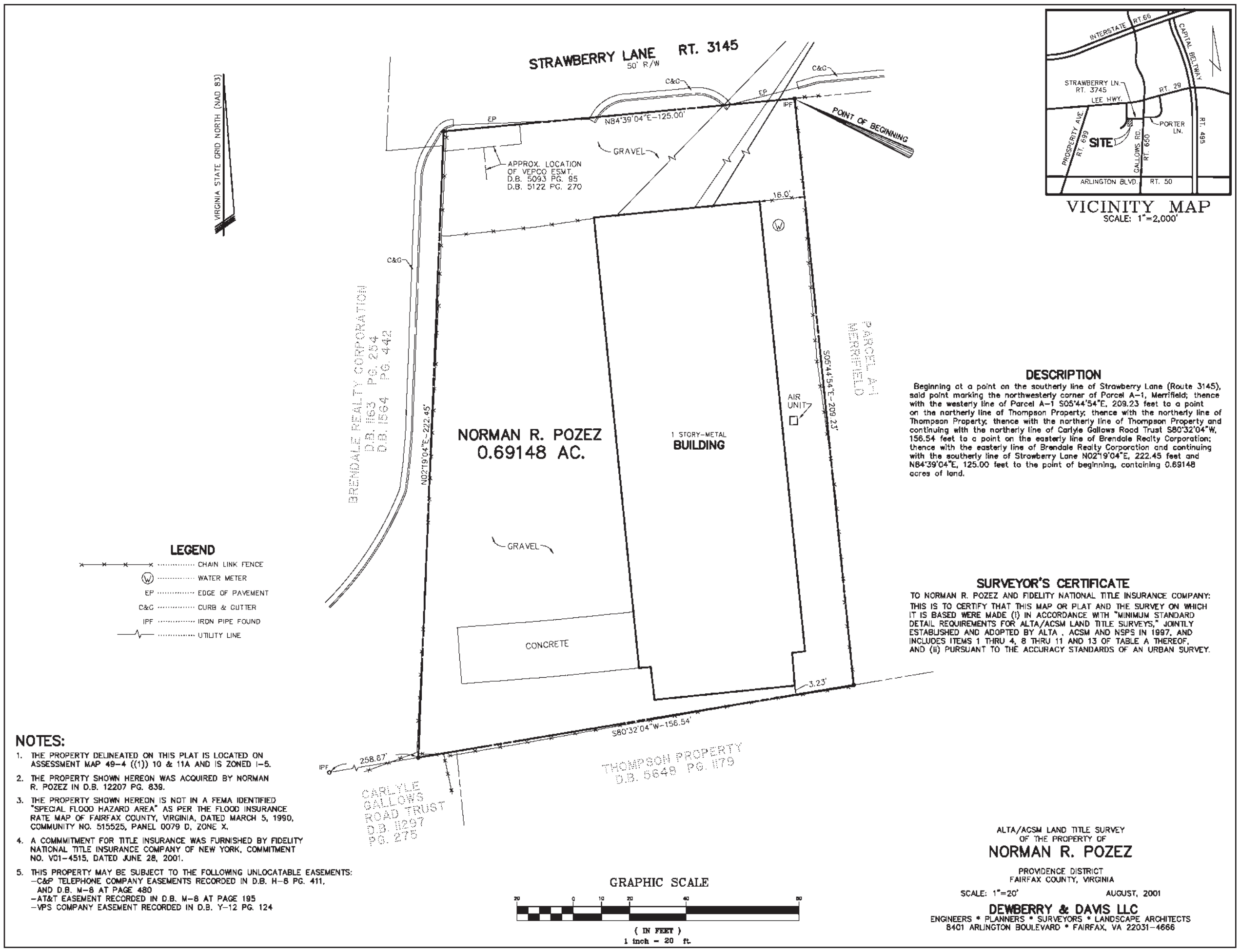

FIGURE 13.7 Final boundary map.

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CHAPTER 14

TOPOGRAPHIC SURVEYS

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INTRODUCTION

While the boundary survey is the skeleton for the physical characteristics of property involved in a land development project, the topographic survey map represents the skin of the property. In mapping, topography is the delineation of natural and artificial features, which define a given place. Although the topographic features of a property may have some significance to project feasibility and site analysis, their primary importance is initially realized in the schematic or preliminary design and engineering phase. The horizontal and vertical position of natural and man-made features play a critical role in determining how a site will be engineered to suit the intended use of the property. Consideration must also be given to the way these features relate to those lying on adjoining properties and within street rights-of-way or easements. Determining how utility services can be provided to the proposed development is among the first preliminary design tasks undertaken.

Topographic information for areas well outside of the project site boundaries is often needed to make preliminary decisions regarding design considerations such as storm drainage patterns. When this is the case, the use of smaller-scale topographic maps, such as those available from the U.S. Geological Survey (USGS) with a scale of 1 inch = 2000 feet or from local government agencies with a scale of 1 inch = 200 feet, is appropriate. As the design process begins to focus more on intricate details, larger-scale maps are needed to ensure that site engineering is as balanced as possible with regard to earthmoving and the use of utilities. Actual map scales are determined by the design team. The size and relative detail of a site often determine the surveying methods employed. For large areas, aerial photography and photogrammetry are economical means of providing detailed maps. These surveys have become increasingly more accurate with improved technology, but they always need to be checked. Moreover, there may be site features that will need additional detail such as areas obscured by tree cover. A careful inspection of each site with the flown topography in hand is essential to quality assurance/quality control. Field methods employing electronic survey systems may be used on other sites to create quality maps in a timely fashion. For small sites, other methods—such as radial conventional or RTK GPS (real-time kinematic global positioning system) surveys—may prove more cost effective.

Experienced personnel, competent in the use of current equipment and who are familiar with modern techniques are an essential ingredient in concluding surveys. Completion of field- and office work includes attention to detail and accuracy. The meshing of field and office tasks is critical for the orderly work progression. Required tolerances for survey work are also important because incorrectly located data or data located from control points that do not meet required tolerances will result in improper design.

Only boundary location is more crucial to land development than the topographic survey. Because the topographic map is an integral part of the design process, omission of valuable information in a topographic survey can lead to costly problems.

PLANNING TOPOGRAPHIC SURVEYS

Planning for topographic surveys includes consideration of the site's physical features, required scale and accuracy, contour interval appropriate for the type of project, cost, and type of instruments available. All of these factors affect the survey methods and equipment used in the topographic survey.

Among the most important aspects of planning a topographic survey is the communication between the designer and those who will collect the field data on which the map will be based. A proper level of understanding of the design concept by those who collect the data will result in a more comprehensive survey and reduce the likelihood that numerous data-gathering exercises will be required. The responsibility for ensuring that this level of understanding is adequate lies with both parties. Neither should make assumptions about whether the understanding exists, nor be timid about asking questions to clarify issues.

When a comfortable level of understanding has been reached, a decision can be made concerning which method is to be employed to conduct the data-gathering survey. Surveys to gather topographic data, like all other surveys, must begin with an appropriate control system. Therefore, the first step in planning for the topographic survey of a land development project is the completion of well-planned horizontal and vertical control networks. These networks must be geometrically strong and well monumented.

The number and location of the control points depends on the nature of the project and on the surveying method used. As a matter of convenience during the design and construction phases of the project, control points should be interspersed throughout the site. It may be cost effective to use traverse points located in the boundary determination as horizontal control stations for the topographic survey. Establishing control points as part of the boundary traverse loop and cross-ties through the middle of the site provide a network convenient for use throughout the design and construction phases of the project. To do this, adequate forethought on traverse location is needed at the time when the traverse is being set for the boundary determination. Provisions for the protection of survey monuments by contractors are necessary and cost effective.

The map scale required for the most demanding use controls mapping requirements. This is because map reduction for planning is generally satisfactory, but enlargements do not usually produce the detail necessary for actual project design. Determination of the most important information requirements before performing the initial survey prevents the need for additional field trips by survey crews. A determination of the contour interval and the area of coverage are controlling factors when planning the fieldwork.

GATHERING THE DATA

Data must be gathered and compiled in such a way that it can be used for preliminary and final design. Historically, surveys have been conducted utilizing a plane table and alidade or a transit/theodolite and tape radial survey for site locations, or a baseline survey for linear projects such as roads and utility lines. None of these methods produces data that can be easily transferred into the digital environment used in today's design process. This does not imply that maps developed using these instruments are invalid. It simply means that their usefulness may be limited for topographic mapping of large sites and long-line surveys, or those with a significant number of features. Technologic advancements including electronic and robotic total stations, GPS in all its many configurations, and electronic data collectors have replaced these instruments for field-run surveys. Photogrammetry, which uses aerial photographs combined with ground control points to generate topographic maps, has become the preferred method for surveying a majority of sites for land development design purposes. The maps created using photogrammetry can be either large scale or small scale. In some cases, the aerial photography is conducted in such a way as to allow both large- and small-scale maps to be created, thus providing a broader view of the project area while serving the preliminary and final design processes. The photogrammetric survey method is not appropriate for determining boundary lines, although it may serve in an evidentiary capacity, allowing a broad overview of an area not available at ground level. Small sites, particularly those with extensive features, are still commonly surveyed using an electronic data collection device. Both the electronically gathered field survey data and the photogrammetric survey data can be compiled into digital topographic maps to serve as the base layer for design files.

The method selected for gathering data influences the specific details of how it is to be accomplished. Regardless of the method chosen, it is critical that data be gathered so that compilation is done in a format acceptable to the designer. This is particularly true when the data is to be collected through a field-run survey. A part of the communication between designer and surveyor, mentioned earlier, should focus on the type of equipment and processing system the surveyor will use and the type of design software the designer will use. Specific attention should be given to the layering system or data library that is required. Data accurately collected and processed is not very useful unless it is presented in a format the designer can use. The reason this aspect of the process is so important for field collection of data is that the coding system for data collection should be established prior to the survey in order to simplify adjustments that might otherwise be difficult during compilation. In the case of photogrammetry or similar methods of gathering data, the issues of proper coding and formatting are also addressed during compilation.

PHOTOGRAMMETRY AND TOPOGRAPHIC MAPPING

The term *photogrammetry* comes from the words *photo* and *meter* and means measurements taken from a photograph. Photogrammetry is the science and art of preparing accurate maps or obtaining reliable measurements of physical features from photographs. Photogrammetric mapping is the most common method used at present for preparing medium- and small-scale maps for use in land development work. In addition, large-scale maps can also be prepared photogrammetrically, depending on the amount of ground cover on the site and the level of detail required. Applications of this surveying methodology include topographic mapping, site development planning, earthwork calculations, digital elevation models (DEMs), and image base mapping. Two types of photogrammetry—terrestrial and aerial—are recognized. Terrestrial photogrammetry is photographic information obtained from ground-based photographs and is used primarily for obtaining information such as building faces, although it has been used in other areas such as monument restoration (Mount Rushmore) and mapping Niagara Falls. Aerial photogrammetry—information from helicopter, airplane, or satellite photography—is by far the most common method for topographic surveys required for land development applications. Aerial and terrestrial photogrammetry utilize the same principals, overlapping photographs and control points that are visible on both the surface and in the photograph.

Two different types of data can be obtained photogrammetrically: *metric* and *interpretative data.* Metric data concerns information related to distance, area, and elevation. This is of primary interest to the surveyor, land planner, and developer. Interpretative data also constitutes a major part of photogrammetry and includes such pertinent pieces of information as ground cover and land use types. Uses of interpretative data also include regulatory enforcement such as wetland encroachment and shoreline monitoring. It is also used for natural and man-made disaster analysis. Today this field of study has expanded to include interpretation of information related to the earth and the environment. The tools used for this field go beyond photographs and include multispectral scanners, side-looking airborne radar, thermal scanners, and other devices resulting from modern technology. The use of these tools for land development design has not yet been fully determined.

The principal instruments involved in photogrammetric mapping are the aerial camera and the photogrammetric plotter. The aerial camera is used to provide the photographs on which mapping is based. The photogrammetric plotter is used to convert the perspective projection on the photograph to an orthogonal projection on a map. Technologies have been developed through which converting the photography into mapping can be accomplished with a computer program. This method is known as *soft-copy mapping.*

Advantages and Disadvantages

Photogrammetry is becoming the method most often used in topographic mapping. Obtaining topographic information from photogrammetry has its advantages and disadvantages, both of which are important considerations when deciding whether to utilize this methodology. Factors to consider in using photogrammetry for surveying include the following:

- The size of the project.
- The type of project. How will the information be used?
- The project time frame.
- The project budget.

The size of the project is a primary consideration in using photogrammetry for topographic mapping. Very small projects (projects of approximately 3 acres and smaller) are not good candidates for photogrammetric surveying. With the advent of GPS and robotic total station surveying, conventional surveying techniques utilizing modern equipment are more appropriate for these smaller sites. Photogrammetric mapping has advantages for large land tracts. Large areas can be mapped for a relatively low cost, as compared to conventional surveying techniques. Some of these areas, such as swamps, highways, and hazardous waste sites, may be difficult, unsafe, or inaccessible to surveyors using conventional methods. Photogrammetry is an ideal mapping method where the safety of the surveyors is a consideration. Unsafe areas can be safely mapped without subjecting surveyors to traffic and other hazards. On roadways, the mapping can be safely obtained without lane closures and traffic disruptions.

Disadvantages of using photogrammetric mapping include lack of detail, the inability to obtain information in obscured areas, the inherent accuracy of the photographs, and the limited flight season. Since all the information for the mapping is taken from photography, the detail is limited to only information visible in the photograph. Items of concern may not be visible due to shadows, overhangs, overpasses, vegetation, and rugged terrain with sharp slopes. These and other obscured areas will still need to be surveyed using conventional ground-surveying methods. Elevations for manholes, inlets, curbs, and other critical areas will also need to be field-surveyed. The flight season is generally limited, due to vegetative cover, crop cover, or snow cover. Therefore, the photographs should be taken at times when obstructive ground covers at the particular site are minimal.

The inherent accuracy of the mapping is also limited. The mapping accuracy is generally in accordance with National Map Accuracy Standards (NMAS), and varies depending on the mapping scale and contour interval required. Typical map accuracies are discussed in the next subsection.

Map Accuracies

Provided minimum third-order ground control (1:5000) is performed, map accuracy will be as follows (see also Table 14.1).

Contours. Ninety percent of the elevations determined from the solid line contours of the topographic maps should have an accuracy with respect to true elevation of half the contour interval or better, and no remaining contour line should be in error by more than one full contour interval. In densely wooded areas where brush or trees substantially obscure the ground, contours will be shown as dashed lines and plotted as accurately as possible from the stereoscopic model. Areas of dense foliage will be identified as "ground obscured" and no contour lines will be shown.

TABLE 14.1 Summary of National Map Accuracy Standards for Photogrammetric Surveying

HORIZONTAL SCALE	FEATURE LOCATION	CONTOUR INTERVAL	VERTICAL (90%)	SPOT ELEVATIONS (90%)
1 in = 20 ft	0.5 ft±	1 ft	½ ft	¼ ft
1 in = 40 ft	1.0 ft±	2 ft	1 ft	½ ft
1 in = 50 ft	1.25 ft±	2 ft	1 ft	½ ft
1 in = 100 ft	2.5 ft±	2 ft	1 ft	½ ft
1 in = 100 ft	2.5 ft±	5 ft	2½ ft	1¼ ft
1 in = 200 ft	5.0 ft±	2 ft	1 ft	½ ft
1 in = 200 ft	5.0 ft±	5 ft	2½ ft	1¼ ft

(Courtesy of Eastern Topographics)

Spot Elevations. Ninety percent of all spot elevations placed on the maps should have an accuracy of at least one-quarter of the contour interval and the remaining 10 percent no more than half the contour interval.

Coordinate Grid Lines. The plotted position of each plan coordinate grid should not vary by more than 1⁄100 inch (0.25 mm) from the true grid value on each map manuscript.

Horizontal Control. Each horizontal control point should be plotted on the map manuscript within the coordinate grid in which it should lie to an accuracy of 1⁄50 inch (0.51 mm) of its true position for the point.

Planimetric Features. Ninety percent of all planimetric features, which are well defined on the photographs, should be plotted so that their position on the manuscript is accurate to within at least 1⁄40 inch (0.64 mm) of their true coordinate position. None of the features should be misplaced on the manuscript by more than 1⁄20 inch (1.27 mm) from their true coordinate position. Partially obscured planimetric details that may not meet this requirement should be shown by dashed lines where possible. Planimetric features totally obscured should not be shown.

General Procedures. Land development applications often require a series of maps showing different data and drawn at different scales. The basic data needed for topographic mapping is generally obtained by contracting with a photogrammetric mapping firm. Normally, the engineering firm specifies scale or contour interval[1] and coverage required for the mapping, as well as the final product (hard-copy maps or computer files) required. Ground control can be contracted or, in consultation with the photogrammetrist, provided by the firm responsible for land development planning and surveying. Both horizontal and vertical control networks are required. Because the control surveys are expensive, every effort should be made to integrate the photogrammetric control surveys with the boundary and construction surveys anticipated for the project. See Figure 14.1.

[1]The desired scale or contour interval is required in order for the aerial mapping company to determine the appropriate photo scale and flying height (see Appendix A).

Once the photography is flown and ground control has been obtained, the photogrammetric mapping firm will use a stereoplotter instrument to produce the finished maps or computer files. There are several types of plotters available, but the analytical plotters provide accurate coordinates to a computer for transfer to geographic information systems (GIS) or use in computer-aided design (CAD) systems for mapping purposes. The maps (or files) prepared by the stereoplotter operator will include corrections for lens distortion, earth curvature, and other mapping errors.

While photogrammetrically prepared maps are basic to most land development planning efforts, it is often necessary to perform simple measurements of distance, elevation, and position from aerial photographs. Performing these simple measurements is actually a complex procedure, the details of which are outlined in the Appendix A.

FIELD METHODS FOR TOPOGRAPHIC MAPPING

General Procedures

Field methods for topographic mapping require that the surveyor accurately locate the positions of both the topographic and the planimetric features on the site. Field methods are necessary in land development where detailed location of surface and subsurface utilities is required, where a limited area is involved, or where slope and drainage are critical. In most cases, this requires the location of a large amount of data, which must be presented on a large-scale map.

The positional bases for topographic mapping are the horizontal and vertical control networks. These may be established prior to topographic mapping. Alternatively, control network extension may proceed simultaneously with the topographic survey. Ideally, horizontal control stations should be located so that the topographer will have sufficient room to work and so that he or she will be able to map the entire area necessary. Points to be mapped are typically located by radial observation from the horizontal control network. The elevations of points sighted are computed trigonometrically or by use of differential leveling (see Chapter 33 for details on the various leveling methodologies).

1. *Determine the total area.* This shall include the project site and any areas adjacent to the site. Typically 100 to 200 feet adjacent to the site is sufficient for land development purposes. Care should be taken when determining this. Too much area can increase the cost significantly, while too little area will require additional flights or costly ground surveying.
2. *Prepare a large-scale map,* typically a USGS Quadrangle 1:24000 scale map, depicting the site and the areas adjacent to the site, the total area to be included in the mapping. This will be used by the aerial company to determine their cost and the likely locations of their ground control targets/points.
3. *Determine the level of detail and scale of the mapping required.* This will affect the price of the mapping. Larger-scale maps are flown at higher altitudes and require fewer photographs; therefore, they are less expensive. The feature detail is also limited. Smaller-scale maps are flown at low altitudes, requiring more photographs because they cover less area, but they provide much greater feature detail. The Mapping Standards should be consulted for determining scale and detail requirements.
4. *Decide how ground control will be obtained.* Aerial companies typically provide these services at an additional cost. It may be more cost effective to obtain the ground control in conjunction with the property boundary survey.
5. *Determine the horizontal and vertical datum to be used.* The mapping can be produced in any coordinate system required.
6. *Decide whether a "new photo" flight is required.* Most aerial companies have stock photos of the areas in which they most frequently do work. Note that stock photos may be up to several years old.
7. *Set ground control targets in the specified locations.* The aerial company may set targets for ground control for new photography or will provide the target locations (points) for the surveyors to set.
8. *Perform the ground control survey* using conventional or GPS surveying techniques, locating the aerial targets or photo points as established by the aerial company.
9. *Complete any necessary adjustments to the ground control survey and provide the aerial company with a list of horizontal and vertical coordinates for the targets (points).* These coordinates will correspond to the same points on the photographs.
10. *Request the appropriate mapping format—digital or hard copy.* The aerial company will perform the necessary calculations based on the ground control survey results and prepare the topographic and planimetric mapping in the desired format.
11. *Review the provided mapping;* the mapping may need supplemental ground surveying to obtain information in obscured areas, objects not visible or obtained, utility structures, and any other information not mapped or in need of verification.

Figure 14.1 Typical aerial photogrammetry procedures for land development.

Instrumentation formerly employed in the topographic surveying field has generally been replaced by what is generically known as the electronic total station surveying system and the real-time kinematic (RTK) global positioning system (GPS) equipped with an electronic data collector (see Figure 14.2). This equipment has the greatest potential for producing high-accuracy results with a minimum expenditure of time in any area where detailed topography is required. The recently developed robotic total station and RTK GPS instruments allow one person to gather data for a topographic map rather than the typical two- or three-person field crew; however, it is sometimes still effective to have crew members performing activities such as drawing sketches and measuring manhole depths while the robotic station or RTK GPS "rover" operator is obtaining other data.

All of these topographic measuring systems have advantages and disadvantages. In comparison, note that while the electronic system requires a high initial acquisition and training investment, the potential for enhanced production will quickly prove the instrumentation to be superior in most surveying situations. The electronic system can provide highly accurate data, which can easily be loaded into a computer. The link between field and office is no longer miles of distance and volumes of notes, but is reduced to the simplicity of an interface cable. The computer dramatically expands the usability and accessibility of the topographer's data. Multiscaled plans for all sorts of land development may be generated from the data without physical manipulation of hard-copy manuscripts.

Figure 14.2 Total station, data collector, and prism. (Photo courtesy of Trimble © 2008)

Electronic Mapping Using Conventional and GPS Methods

To begin a conventional survey using a total station, the surveyor first occupies an existing control station. He or she then orients the instrument to another station in the network. Orientation is typically made by pointing on a tripod-mounted prism at the backsight station. Alternatively, sighting on a prism mounted on a plumbing pole can be used (see Figure 14.2). The height of the plumbing pole (and the tripod-mounted prism if used) must be recorded in the data collector, together with other information required for the job.

Beginning an RTK survey is similar in that the surveyor sets up the base station on an existing control point; however, as a check, it is good practice to have another control point nearby, within 10 feet or so of the base point to check to. Staking to the checkpoint with the rover ensures that everything is working correctly before the job begins.

The data collector usually has a series of user prompts to begin collection at each station. Typically, the prompts begin by asking for a file name, a user's name, date, temperature, and barometric pressure, which is then followed with prompts for the setup: instrument base point number or traverse station number, height of instrument, backsight point number in the case of a conventional job, and prism or receiver height. When the instrument operator then backsights the prism, the data collector records the raw data, consisting of the horizontal angle, vertical angle, and distance. The distance and the difference in elevations between the two known stations are verified with the known data.

With the internal data file initiated, the instrument oriented, and the data collector initialized, the topographic data collection begins. Each type of feature usually has a numerical or alphabetic code. Codes may be augmented with a brief description. The data collector prompts the operator for point number, description and code, prism height, and a choice of preset measurement sequences. The last of these entries activates the total station instrument or rover, and the raw data is recorded. This information is displayed on the data collector for the operator to approve, reject, or edit. If approved, the collector advances to the next point number, ready for the next shot. If rejected or edited, the bad shot is retained and labeled as such, and the next point number is utilized for the correct information. This is useful for cross-checking the data. Sample codes and abbreviations for data collector use are shown in Figure 14.3.

For complex sites or features, a detailed sketch must be prepared to accompany the collector printouts (see Figure 14.4). The sketch should include outlines of buildings and structures, dimensions, measurements, types of materials, sizes of pipe, descriptions, data collection point numbers, and any other pertinent facts. It is imperative that the field crew understand that the person who will draft the map will very likely never visit the site and his or her sketch is key in the drafter's understanding of the site. Therefore, the sketch must be clear, concise, and complete.

An efficient way to collect the data is to shoot each feature continuously, as much as circumstance permits. This enables the data collector operator to repeat-key some of the shots and offers the software consecutive shots for creating line sequences. For example, along a road the prism handler may locate the edge of pavement along one side, as far as practical, directed away from the instrument. The centerline can be located with continuous points in the directions toward the instrument and then return up the other edge of pavement. This method for location is sometimes helpful to the person who processes the data in the office because it keeps a consecutive series of point numbers for a particular feature. It is not mandatory, however, to collect data in this manner. Most software used to process raw field data recognizes points with the same code and combines them to draw the feature represented by the code. The shots should be placed at horizontal changes in direction or vertical changes in elevation and/or at the distance interval commensurate with the map scale; for example, a map scale at 1 inch = 50 feet requires at least one shot every 50 feet.

Since topographic surveyors must translate a three-dimensional terrain to a two-dimensional map, the actual success of a topographic survey depends on the location of essential points, which define a particular terrain. Every ridge, grade break, toe, or top of slope is studied carefully for the exact placement of the location point that tells the story. Every man-made feature is similarly interpreted and delineated by a series of adeptly placed shots. Because a computer generates the contour lines, care must be taken to space the shots in such a way that they do not appear to cross each other, particularly in curves (see Figure 14.5). In addition, the prism handler must select obstruction-free sight lines to the instrument, change the height of the prism or rover as necessary, and maintain constant communications. Obviously, having an experienced topographer as the prism or rover handler expedites matters. This person can also confidently call shots—relate new information to the previously made shot. Many data collectors possess a feature that enables one to reference a shot left, right, back, ahead, up, and down in relation to the last instrument-shot point. This is particularly useful in thickets, woods, obstructed places, and steep terrain where sight lines may have to be selected and/or cut out with brush hook or machete. Under such circumstances, an experienced topographer distinguishes between the essential, the necessary, and the optional shots, and makes the shots accordingly.

Topographic mapping using electronic data collection has become the standard for field-run surveys. Software continues to be developed that improves the field-to-office conversion of data into mapping. Purchasing the proper equipment and developing a system for field and office procedures that enhance the ability to make those conversions faster and more efficiently is critical to the ultimate success of a land development project.

The use of GPS equipment to collect topographic data has become more prevalent. Advances in the satellite constellation, the real-time computation of point positions, and the reduction of equipment costs have led to a wider use of GPS equipment for a variety of surveying activities. As the investment in equipment decreases and new technologies enhance

01 - Horizontal Control TRV PXP - Panel Point	11 - Centerlines CL. Centerline Road	33 - Electric ELE ------------ 35 - Building BLD
05 - Property/Boundary IPF EIP Existing Iron Pipe EIR Existing Rod/Rebar/Pin GDR EPT Existing Pinch Top EIO Other (Describe) MKT Marked Tree N North S South E East W West MON Existing Conc. Mon. NIP New Iron Pipe PK. P.k. Nail RW Right of Way Mon. STN Stone	17 - Pavement EP. Edge of Pavement EPL EP Left EPR EP Right ------------ 18 - Curb TC. Top of Curb TCL Top of Curb Left TCR Top Curb Right BC. Back of Curb (Top) FC. Face of Curb (Flow) ------------ 19 - Concrete CON CCP Corner Concrete Pad EC. Edge of Concrete SW. Edge of Sidewalk	37 - Utilities Misc UTL OU. Overhead Utility PD. Telephone Pedestal UU. Underground Utility CTV Cable TV MCP Utility Marker Post UMN Utility Manhole VLT Utility Vault ------------ 42 - Miscellaneous MIS MB. Mail Box RS. Road Sign GL. Ground Light
07 - Grade Elevations SPT GR. Ground Spot Shot GRP Pavement Spot Shot GRC Concrete Spot Shot GRG Gravel Spot Shot	20 - Shoulder SHL ------------ 21 - Parking Stripes/Paint Lines PRK ------------ 22 - Utility Poles UPL GP. Guy Pole GW. Guy Wire LP. Light Pole PP. Power Pole SP. Service Pole TP. Telephone Pole	44 - Wetlands WET ------------ 58 - Break BRK TB. Top of Bank BB. Botton of Bank ------------ 60 - Walls WAL CW. Centerline Wall EW. Edge of Wall
08 - Stream/Pond/River STR Stream DL. Ditch Line WL. Edge of Water	23 - Water WAT HYD Fire Hydrant MW. Monitoring Well PIV Post Indicator Valve WL. Waterline WE. Well WM. Water Meter WV. Water Valve	61 - Test Pit TP. ------------ 62 - Unimproved UNI PAT Trail or Path EG. Edge of Gravel DT. Edge of Dirt
09 - Vegetation VEG OB Ornamental Bush OT Ornamental Tree HDG Hedge WDL Woodline TR Tree A (Cherry), Size (In.) B (Beech), Size (In>) C (Cedar), etc... D (Cottonwood) E (Elm) F (Ash) N (Tupelo) G (Locust) P (Pine) H (Hickory) Q (Oak) J (Burch) R (Dogwood) K (Sasafrass) S (Sycamore) L (Sweet Gum) T (Poplar) M (Maple) Z (Misc.)	26 - Storm STM BXC Box Culvert CMP Corrug. Metal Pipe CPP Corrug. Plastic Pipe DIP Ductile Iron Pipe DIG Drop Inlet-Curb Grt. DIS Drop Inlet-Curb Std. RCP Reinf. Conc. Pipe SDM Storm Drain Manhole TCP Terra Cotta Pipe YIG Tard Inlet-Grate YIS Yard Inlet-Std. I (Invert), Size (In.) T (Top), Size (In.) ------------ 29 - Sanitary SAN CO. Cleanout SSM Sanitary Sewer Manhole	63 - Railroad FR. Frog PS. Point of Switch RR. Railroad IR Inside of Rail CL Centerline of Rail ------------ Desc. Format for Point L L - P P P D S . . . . . --Sub Desc. ----Draw Code --------2 or 3 Char Point Descriptor -- ,-, Das Character -- 2 Digit Layer Code Use a "." (Period) as a Place Holder When There Is Only 2 Chars in the Point Descriptor and in Place of the Draw Code When There Is None.
10 - Fence FEN Fence GDR Guard Rail GPP Guard Pipe Post	32 - GAS GAS GL. Gas Line GM. Gas Meter GV. Gas Valve	Draw Codes (7th Position) L - Line C - Curve Z - End Draw Sequence Y - Close into Initial Point

FIGURE 14.3 Codes and abbreviations used for data collectors.

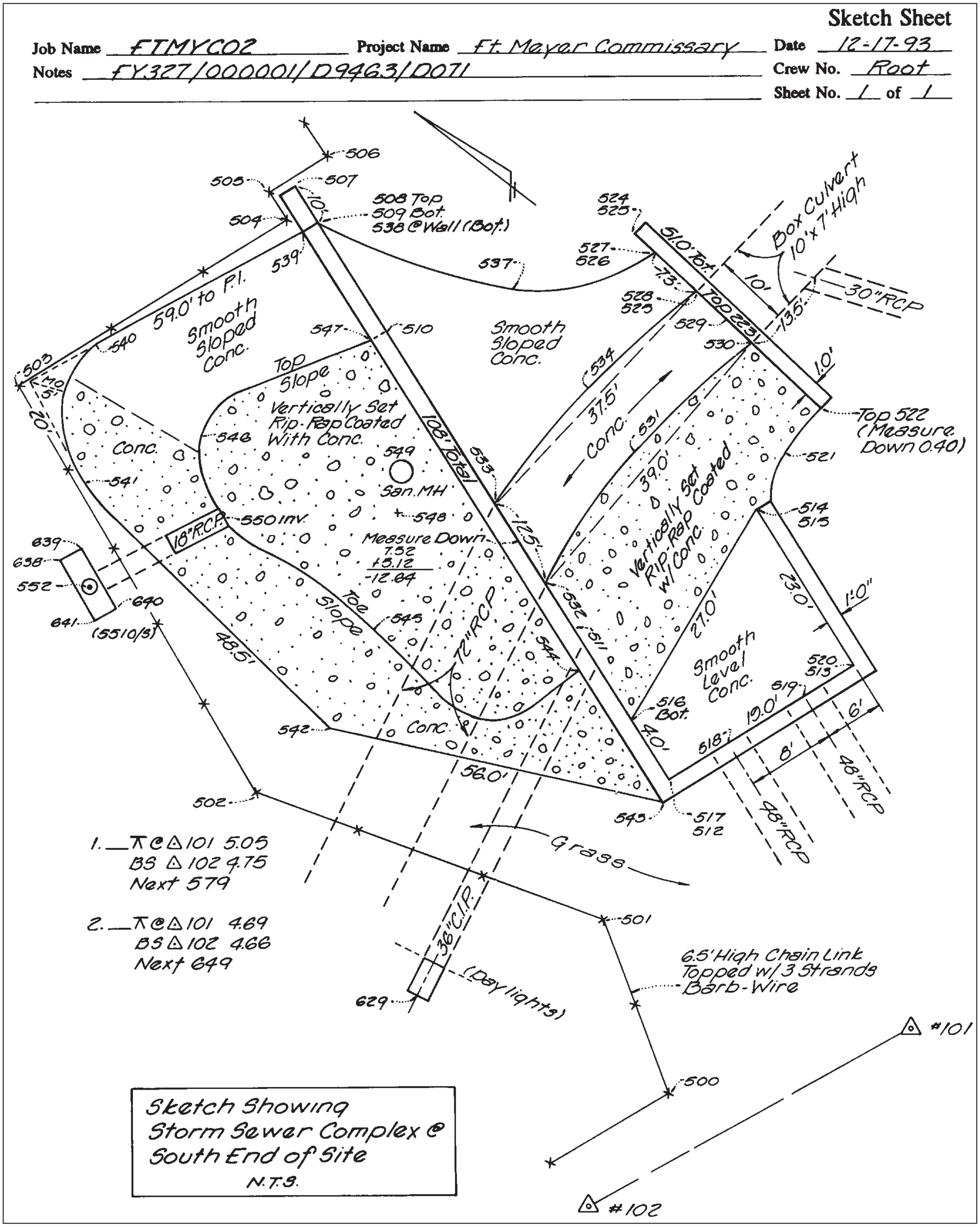

FIGURE 14.4 Sample field sketch to accompany data collection raw file.

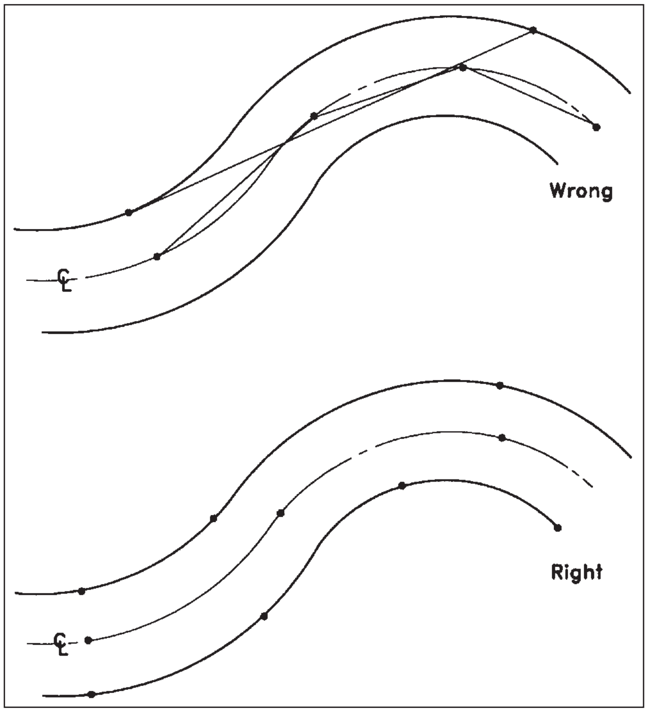

FIGURE 14.5 Data collection shot placement along curves.

FIGURE 14.6 RTK rover and data collector. (Photo courtesy of Sam Dougherty and Steve Hall of Dewberry and Trimble © 2008)

the surveyor's ability to use the equipment, the use of GPS for data collection related to topographic mapping may become a standard practice. Real-time kinematic (RTK) surveying is the primary means of gathering topographic data by GPS methods. It allows data gathering in essentially the same way as with a total station, that is, via a data collector. The methods employed by the person operating the rover are the same as those of the person operating the prism pole or robotic rover. The major consideration with using RTK is that it must have an unobstructed view of the sky. The GPS signal broadcast from the satellite constellation is relatively weak and cannot penetrate heavy leaf cover or buildings. It is also subject to multipath, the reflection of signals off of hard objects such as buildings, walls, or vehicles, which can distort the positions derived by the instrument; therefore, provisions must be made to avoid these areas when surveying with GPS RTK and mark them to be surveyed later by other means such as a conventional total station. See Figure 14.6.

Coordinating Field and Office Procedures for Electronic Survey Systems

Because of advances in computer science and survey software, such as CADD, it is easy to be misled by the premise that the machine, combined with knowledgeable programmers and operators, can provide a solution for every problem. The office practitioner, however, is well aware that no software comes close to handling the everyday situations in the real world. The honest computer operator will also acknowledge that the quality of the end product rests predominately within the skills and knowledge of the field topographer, and not with the computer. An experienced topographic surveyor performs two functions. First, the surveyor will have mastered the art of field data collection, good surveying practice, and the proper employment and care of the equipment. Second, the surveyor feels equally at home in the office, making daily use of the mathematical sciences. The surveyor will be conversant with the operation of various computing systems and software capable of producing a topographic map. This individual will have access to the client, planner, and/or engineer who will be using the survey. Having made inquiries of all end users and having been supplied with field sketches and electronically collected field data augmented by visual field inspection, the surveyor generates a three-dimensional graphical/mathematical model of the project, henceforth referred to as the *topographic survey map*.

Realistically, however, a somewhat different situation exists in a typical multiservice land development firm. Here, production is balanced against optimal achievement, yielding a useful, cost-efficient product. In this setting, the field topographer's job is often completed by an office technician. A good deal of care is needed in communications, if the work is to be completed on time and within budget.

Before fieldwork begins, office procedures commence with a meeting between the field party chief and the surveyor of the computing department. A lack of communication between these two usually results in error, frustration, and inefficiency. The large majority of topographic surveys are done in concert with other field tasks such as boundary survey or stakeout for clearing, soil borings, or improvements. In most instances, knowledge of foregoing survey operations resides within the files of the computing department.

The party chief, in collaboration with the computing department personnel, must establish a data format. Each point located in the field must be uniquely identified as to horizontal location, vertical elevation, and physical character. Depending on data collector and computer software flexibility and compatibility, some or all of these values may be catalogued within the data collector for delivery to the computer. Point numbers, subject-specific or layer-specific numeric codes, and physical descriptions and notations are often used. In most instances, a standard set of codes and descriptive abbreviations alleviate problems with interpreting field data.

Before entering the field, the computing department may download existing traverse control and other pertinent coordinate data into the data collector. Whether or not such coordinate data is available or used within the data collector, the computer must be able to assign a unique identity to each three-dimensional collection point. Most coordinate geometry software uses point number identification. In this case, a block of point numbers must be reserved. Failure to do this eventually results in the destruction of overlapping data, extensive editing of point numbers in the field data book, and a typically unpleasant confrontation between office and field personnel.

The party chief should review the project with the computing department surveyor in order to set survey priorities. What datum will be used? What accuracy and precision are acceptable under the scope of services? What will the horizontal scale and contour interval be? Will extra observations be needed to demonstrate minute vertical detail (i.e., top of curb, inlet grates, pond risers and pipe inverts, manhole rims and inverts, slab elevations, height of buildings)? Is the project devoid of detail or is it covered with buildings and roads? If there are numerous structures, have they been located previously or will a location survey be part of the task? How will the data be collected in order to develop contours along the face of buildings, walls, curblines, critical section ditches, and streams? What will the topographic data be used for? Can the data be collected in a random pattern, minimum grid interval, or stationed baseline/offset cross section? All of these considerations can have immense impact on the suitability of the finished topographic map. The technician who simply computes what is given to him or her without asking such questions beforehand will likely receive much grief at the hands of the supervisor.

The field data usually comes to the office stored within the data collector, although there is technology available to transfer the data from the field to the office via cell phone and the Internet. The readings may have already been reduced to coordinate data by software within the data collector, or reduction may be the job of the office technician. All data will then be loaded, via interface cable, into the computer. This data will usually be composed of the data collector file, a readable field book file, and any newly created coordinate data. The party chief will report any uncorrected entries to the computer operator. The reduction of the field data into coordinate data should be done when the party chief is present; only he or she can report and resolve problems in the data collector file resulting from missing, corrupt or incorrectly entered data. On occasion, data does become corrupt and unusable. Illegal data entry, bad file exit procedure, or bad data-editing procedures are most often the cause. Worn cables, bent interface connectors and ports, and shorted entry buttons may also be to blame.

Perhaps the single most important piece of information coming out of the field is a graphical sketch and other handwritten field notes. Although handwritten information may seem archaic in these modern, electronically oriented times, these hand-drawn hard copies show physical improvement detail, corresponding point numbers used in data collection, benchmarks, vertical control loops, dimensions of physical features (buildings, pipes, walls, pavement widths), and lines and features to be honored by the computer for interpolating contours. In the absence of the party chief, the field sketch is the technician's only dependable instruction for putting together a puzzle, which may involve thousands of three-dimensional data points. As stated earlier, the office technician might never visit the site in person, therefore an accurate, concise field sketch is indispensable in interpreting the field data.

Once all field data is reduced, all points defining breaks in the lay of the land must be connected within the computer screen file. If an adequate coding system has been devised, the connection of these points will automatically occur in the computer processing of the raw data, so that the person in the office will not need to do so. These lines are referred to as *breaklines.* All contours are interpolated along these lines. A contour of a given value will naturally break in a certain direction as it runs between the interpolated points of equal elevation. Examples of breaklines include top or bottom of bank; top or bottom of curb; building/wall faces; edge of pavement; centerline of stream, ditch, or road; or any continuous linear or curvilinear break in the elevation of the land. Every line segment will have two corresponding coordinates defining the location and elevation of the ends of the lines. Using interpolation, the computer can easily locate where any given contour elevation falls.

Having set up these known natural and man-made control lines, the technician initiates a computer network of similar breaklines, connecting all other miscellaneous points within the file that are intended for topographic compilation. The technician protects the integrity of the input data by making use of elevation, numeric, or proximity filters to eliminate the use of extraneous data points within the coordinate file. No network line will cross another. Network lines are constructed in such a manner that they form a continuous pattern of triangular sections whose vertices are composed of field points. The maximum allowable length of the network lines (selected by the technician) dictates the accuracy of the topography. The density of field observations, however, limits the length of the network lines. The computer cannot create a network in areas where data collection is insufficient to accommodate a given line length. No contours are obtainable in such an area. The technician must then decide if more field data is necessary or if a longer network line is acceptable.

When the entire network is complete and all errors have been dealt with, the technician has a good network file, or TIN (triangulated irregular network) file from which contours of any interval may be derived. Having selected an interval and scale suitable for end users, the computer creates by interpolating the location of all points within the network for each contour. Contours are then drawn (straight line) within the triangular network sections by graphical depiction on the screen. The technician may elect to have the computer automatically smooth out the faceted, unnatural, or deceptive breaks in the contour lines. Further refinement may be obtained by hand-tracing the desired contour alignment on the screen with a mouse or other instrument. The topographic survey map is then ready for plotting. The TIN file should be kept inviolate; it can be used again and again to generate additional topographical maps of varying contour intervals, as well as centerline profiles, grading scenarios, and earth takeoffs.

BASELINE TOPOGRAPHY

A baseline topographic survey relates horizontal and vertical data to a known reference line, that is, a baseline. This method is particularly suited for long-line surveys, such as roads, utility corridors, and streams. The baseline is stationed along its length. For each feature, the station and the distance left or right of the baseline is noted and an elevation obtained.

The baseline can be the centerline of a road, an offset line, a property line, or a traverse line, whichever is the most practical. The line is stationed in increments, such as 25 feet, with a hub or nail set at each one. Elevations are then established at each station.

Handwritten baseline field notes are unique in that they begin at the bottom and run up the page. As shown in Figure 14.7, the notes are set up with the profile level run on the left page and the cross-section notes on the right page. To accommodate the cross sections, plenty of space is left between the profile stations. On the cross-section page, a

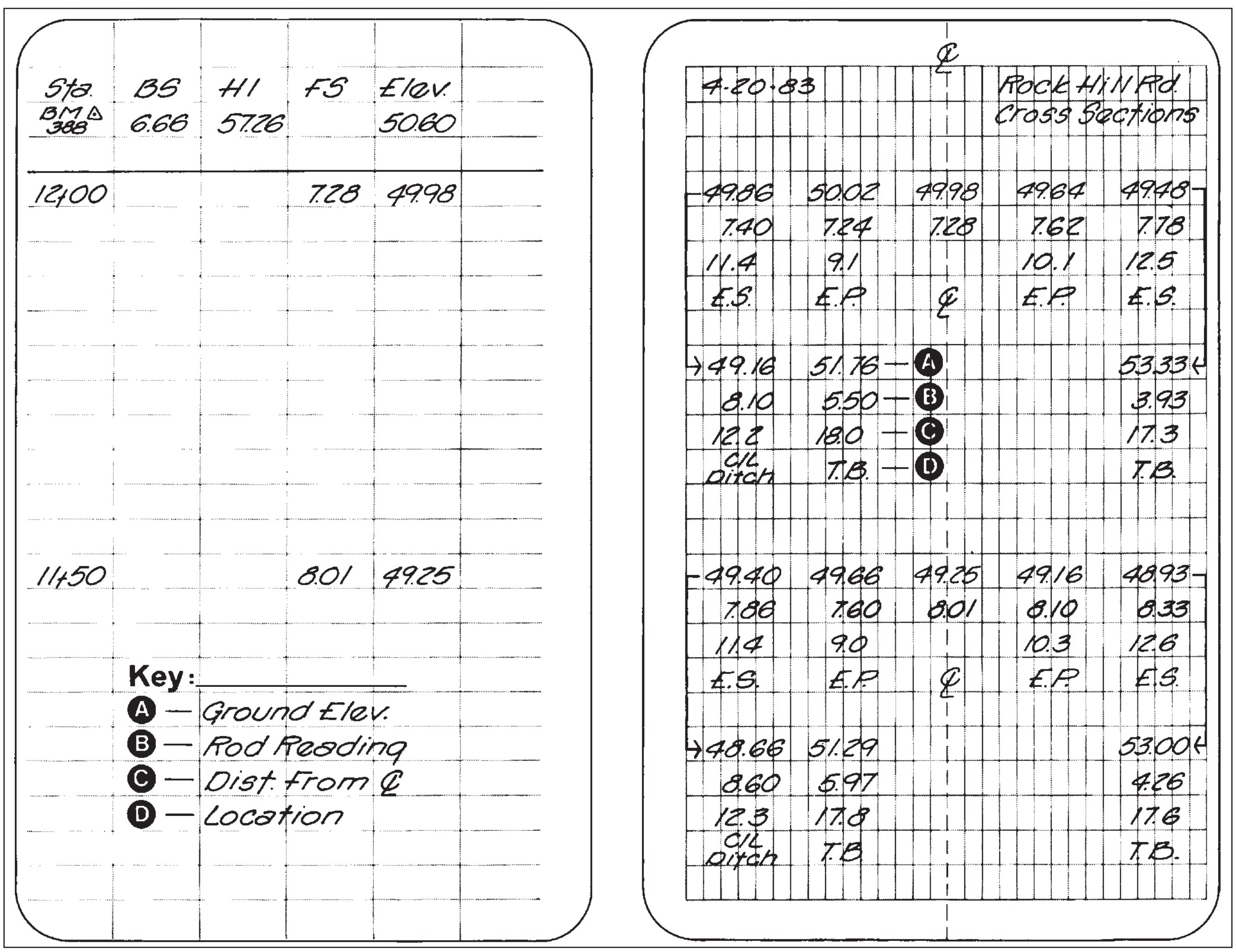

FIGURE 14.7 Baseline field notes.

line is struck from top to bottom to represent the baseline. Each location is written to the right or left of the line, depending on its location in the field. The data for each shot consists of a station along the baseline, a rod shot, a distance off the baseline, and an abbreviated description. The distances with the descriptions are obtained first, and the shots are marked with keel or flagging. When all the horizontal measurements are complete, the leveling run commences. With elevations established at each baseline station, they can also be used for benchmarks. On pavement, concrete, storm, or sanitary structures the rod is read to the nearest hundredth of a foot. On ground shots, the rod is read to the nearest tenth of a foot. After the levels are run, the rod shots are subtracted from the H.I. (height of the instrument) and the elevations are written above the rod shot. In the office, the math is checked, and the profile and cross sections are plotted to the appropriate scale.

DETERMINATION OF STRIKE AND DIP OF OUTCROPS

Strike and dip represent the orientation of weakness planes in geological seams. Figure 14.8 shows the relationship of strike to dip. Dip is perpendicular to the strike. Strike is the compass bearing of a plane, while dip is a measure of the inclination of the plane. The dip angle is the angle of inclination of the plane measured from the horizontal.

Finding the strike and dip depends on given information and the type of solution method chosen. The example included for illustration in this chapter uses trigonometric procedures. Other options for determining results include graphic methods that involve descriptive geometry and solutions that employ a nomograph.

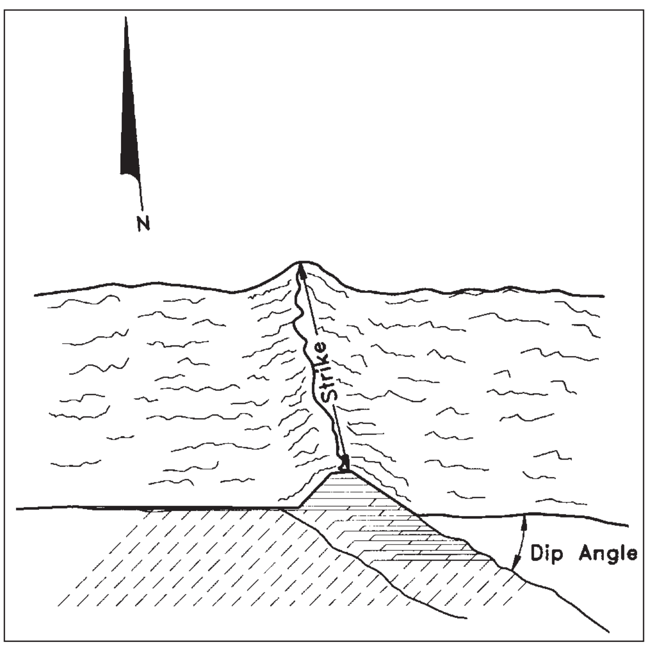

FIGURE 14.8 Strike and dip.

TABLE 14.2 Data for Three Core Holes to Determine Strike and Dip

$$\tan \alpha_{x\text{ to }y} = \frac{\text{Elev.}_{RCH} - \text{Elev.}_{MCH}}{\text{Dist.}_{RCH\text{ to }MCH}} \tag{14.1}$$

where:
α = apparent dip
RCH = reference core hole
MCH = marker bed core hole

$$\tan y = \cot \alpha_1 \times \tan \alpha_2 \times \operatorname{cosec} \mu - \cot \mu \tag{14.2}$$

where:
y = angle measured $A_{1\text{ to }2}$ to the true dip direction
A = azimuth (or bearing) between core holes
α_1 = apparent dip between reference core hole and a second core hole
α_2 = apparent dip between reference core hole and a third core hole
μ = angle between azimuths for apparent dips $A_{1\text{ to }2}$ and $A_{1\text{ to }3}$

$$\tan \delta = \tan \alpha_1 \times \sec \gamma \tag{14.3}$$

where: δ = true dip
α_1 = apparent dip between reference core hole and a second core hole
γ = angle measured $A_{1\text{ to }2}$ to the true dip direction

EXAMPLE

The data from three core holes is listed in Table 14.2. Calculate the true strike and dip of the marker bed.

The computations involve solving the following three simple equations.

1. Assume a reference point. For the example, let that be core hole #1 (see plot of Figure 14.9).
2. Calculate the apparent dips using Equation 14.1.

$$\tan \alpha_{x\text{ to }y} = \frac{\text{Elev.}_{RCH} - \text{Elev.}_{MCH}}{\text{Dist.}_{RCH - MCH}} \tag{14.4}$$

$$\tan \alpha_{1\text{ to }2} = \frac{125}{1100.0} = 0.11364$$

$$\alpha_{1\text{ to }2} = 6.483°$$

$$\tan \alpha_{1\text{ to }3} = \frac{250}{1840.0} = 0.13587$$

$$\alpha_{1\text{ to }3} = 7.737°$$

With two apparent dips determined and the horizontal angle between them also known, Equation 14.2 supplies the direction of the true dip. This angle, determined in Equation 14.2, is measured from the azimuth $A_{1\text{ to }2}$, thus establishing the line of the true dip direction.

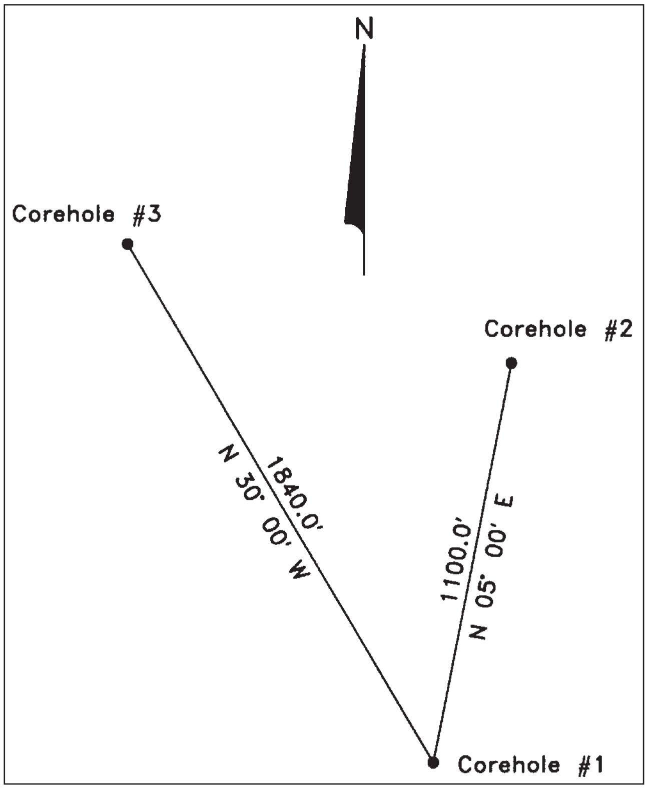

Figure 14.9 Sketch for core hole data.

$$\tan \gamma = \cot \alpha_1 \times \tan \alpha_2 \times \operatorname{cosec} \mu \times \cot \mu \qquad (14.5)$$

$$= \cot 6.483^\circ \tan 7.737^\circ \times \operatorname{cosec} 35^\circ - \cot 35^\circ$$

$$= 8.80000 \times 0.13587 \times 1.74345 - 1.42815$$

$$= 0.65641$$

$$\therefore \tan^{-1} \gamma = 33.2812^\circ = 33^\circ 1'6\ 52.4''$$

Use Equation 14.3 to find the true dip.

$$\tan \delta = \tan \alpha_1 \times \sec \gamma \qquad (14.6)$$

$$= 0.113636 \times \frac{1}{\cos 33^\circ\ 1'6\ 52.4''}$$

$$= 0.113636 \times 1.196190 = 0.135931$$

$$\therefore \tan^{-1} \delta = 7.74$$

Figure 14.9 is a plot of the example and Figure 14.10 represents a graphic solution. Plot the two apparent dips from an origin with their lengths equal to the cotangent of their respective values. Next, join the termination point of the respective apparent dips. The connecting line represents the true strike. A perpendicular line from the true strike line through the origin represents the cotangent of the true dip. Values determined by scale yield close approximations of the mathematical results.

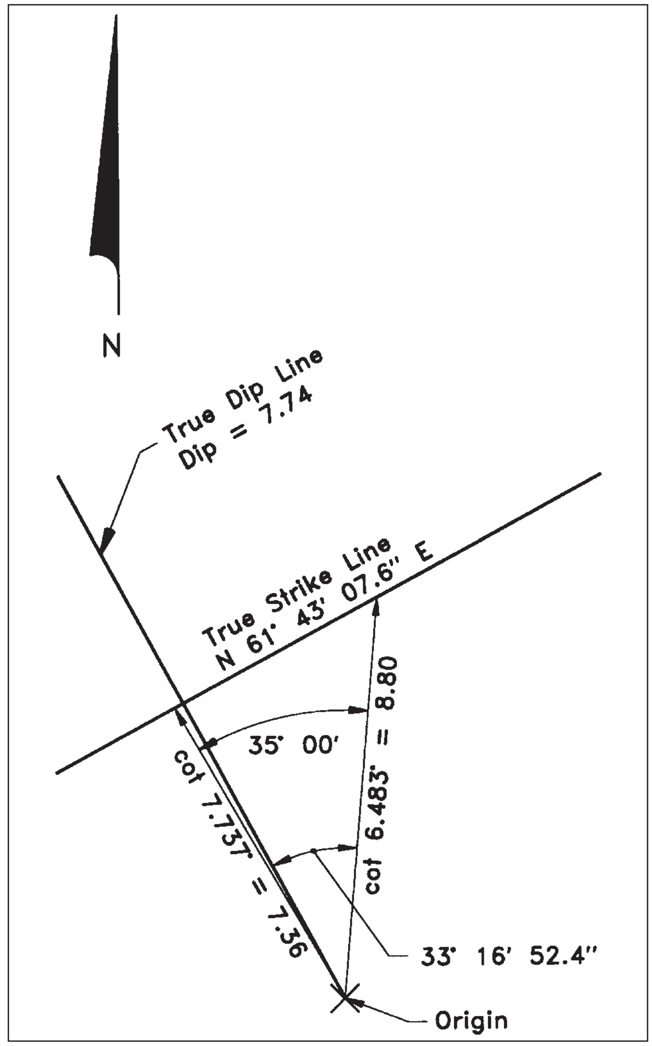

Figure 14.10 Graphic solution to determine strike and dip.

SUMMARY

Topographic maps are an essential part of the design process. The construction phases of land development projects rely on topographic maps for grades and location of important topographical features. If such maps are not of a high quality, they can cause costly mistakes and time delays. Time spent planning the fieldwork and mapping for these surveys reduces the likelihood of errors and omissions in the final product.

The time for making determinations concerning type or combination of types of survey methods appropriate for collection of the necessary field data in the most effective and efficient manner is during the planning process. This is also the time for establishing a contour interval that will satisfy accuracy requirements.

The process moves forward from the planning stage to the fieldwork. Field crews establish a survey control network

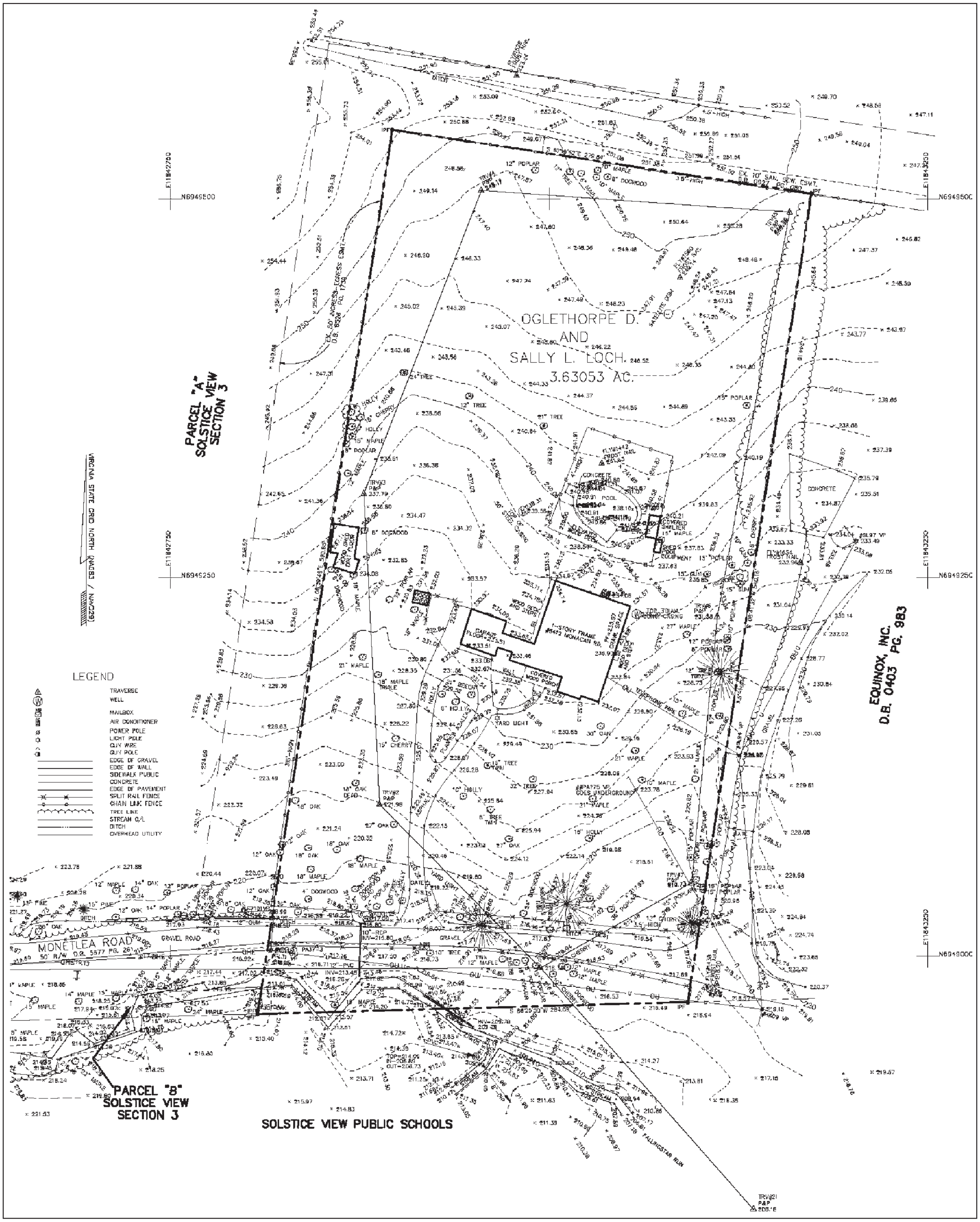

FIGURE 14.11 Topographic map—finished product.

for both horizontal and vertical surveys that follow. These surveys require coordination with boundary surveys and in some instances they are combined. Existing features are located, including buildings, roads, utilities, waterways, vegetation, and other features that might impact the development. Elevations required for developing contours are determined. This data is reduced to a form necessary for mapping.

Decisions on the size of drawings, scale ratios, labels, and necessary notes precede the mapping process. Plot points in their proper location as defined by the horizontal control. Label elevations of respective points and begin the interpolation process appropriate to the data collected. Draw the contour lines on the determined interval. Impose information on other features related to the topography. Finally, on completion of the drawing, make a check of the information shown prior to release of the map. See Figure 14.11.

The method for gathering the data for a topographic map is simply a choice based on the circumstances associated with the property to be mapped. Whether one chooses an electronic survey system, photogrammetry, or one of the systems more commonly used in previous years, the concepts for determining what features will be mapped and what other considerations are to be given remain consistent.

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PART IV.B. REFINEMENT OF PREVIOUS ASSUMPTIONS

CHAPTER 15

ENVIRONMENTAL AND NATURAL RESOURCES

Kimberly V. Larkin

A town is saved not more by the righteous men in it than by the woods and swamps that surround it.
—*Henry David Thoreau*

INTRODUCTION

An increase in the awareness of the benefits that natural resources such as open space and vegetative buffers, and historic resources provide, both individually and in aggregate, has caused the issue of resource preservation and augmentation to become an integral part of the land development process.

As our built environment expands, it is imperative that land development activities not compromise the long-term quality of our natural environment. The responsibility of land stewardship is shared among various stakeholders including environmental, engineering, and legal professionals; corporations; community and urban planners; architects; public officials; and private citizens. Therefore, any individual who participates in the land development process should understand and appreciate the important functions and values provided by natural resources in climate, air, and water quality preservation.

Wetland, wetland buffer areas, and forests as well as other forms of open space are a vital part of our economic future. As such, these features have become increasingly regulated at the federal, state, and local levels through laws, ordinances, and formal recommendations included in comprehensive plans linking the natural and built environments. While wetlands and water bodies are regulated at the federal and state level, trees, landscape, and open-space preservation ordinances have become commonplace in many localities. The emerging green building rating systems have brought increased attention to the value of open space, habitat, and native vegetation not only in an environmental context but in terms of human health and happiness.

Land development consultants are uniquely positioned, given their technical background and practical experience, to cultivate an appropriate balance between preservation and construction efforts. This chapter discusses the applicable regulatory framework surrounding natural resource determinations and the resultant site-planning considerations that should be included in any land development project. Beyond understanding the requirements, it is increasingly important for consultants and all stakeholders involved in a land development project to truly understand the value of the various functions natural resources perform. From aesthetics to security to pollution prevention/remediation and climate control, natural resources are a critical component of land development projects that warrant consideration throughout the process.

WETLANDS

One of the primary constraints to site development is the presence of wetlands or other waters of the United States, including stream channels, ponds, and lakes. Waters of the United States are regulated by the U.S. Army Corps of Engineers (Corps) under the Clean Water Act. Originally known as the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), it was amended in 1977 and renamed the Clean Water Act (CWA), although you will not find a law specifically named the Clean Water Act. The specific regulatory language related to wetlands is included under U.S. Code Title 33 (Navigation and Navigable Waters), Chapter 26 (Water Pollution Prevention and Control), Section 1251. Chapter 36 of Title 33 deals with the Corps of Engineers' authority to regulate development in accordance with

Chapter 26, Section 1251. Within the broad scope of the Clean Water Act, the most pertinent wetland regulation to land development activities is Section 404, which regulates the discharge of dredged or fill material into navigable waters of the United States. As a result of a lawsuit settlement in 1975 (*Natural Resources Defense Council v. Calloway,* 392 F. Supp. 685 D.D.C 1975), Corps jurisdictional authority was extended to nonnavigable waters and wetlands as well.

This authority has been challenged several times on the basis of the actual jurisdictional reach intended by the CWA and continues to be challenged today. Most recently the authority of the Corps to regulate isolated wetlands has been of great debate. Isolated wetlands are those wetlands that have no visible evidence of a surface water connection to navigable waters.

Another ruling (January 2001) by the U.S. Supreme Court (*Solid Waste Agency of Northern Cook County v. U.S. Army Corps of Engineers*) found that the isolated waters in question did not meet the definition of "navigable waters" under the CWA. In addition, this ruling found that the use of the Migratory Bird Rule linking the regulatory authority to intrastate commerce was not supported by the CWA. The result of this ruling allowed the filling of isolated wetlands, many of which are havens for rare and endangered species and act as filters for ground water resources.

Historically, federal wetlands regulations allowed draining and channelization of wetlands and waters of the United States. However, as the result of a lawsuit settlement in early 1992 (*North Carolina Wildlife Federation, et al. v. Tulloch,* Civil No. C90-713-CIV-5-BO [E.D.N.C. 1992]), the Corps and the Environmental Protection Agency (EPA) agreed to extend their regulatory authority to include mechanized land clearing, ditching, and channelization in wetlands and waters of the United States as regulated ditching activities that may result in "incidental fallback" *or* a discharge of fill material from the excavation activity. This extended regulatory reach was challenged in 1998 and defeated, allowing wholesale excavation and draining of wetlands provided the dredge material was placed in an upland area, not side-cast into wetlands or waters. According to the EPA Office of Water, between the 1998 ruling and April 2001, upward of 20,000 acres of wetlands and 150 miles of streams were targeted for destruction as a result of this loophole. Consequently, the EPA and the Corps published a ruling that modifies the definition of "discharge of dredge material." This definition, found in 33 CFR part 323.2, now states that "the Corps and EPA regard the use of mechanized earth-moving equipment to conduct land clearing, ditching, channelization, in-stream mining or other earth-moving activity in waters of the United States as resulting in a discharge of dredged material unless project-specific evidence shows that the activity results in only incidental fallback." In other words, all who propose to conduct excavation work in waters of the United States must notify the federal regulatory authority and prove that the ditching results in only "incidental fallback."

For now, the Corps has backed down on regulating isolated waters and wetlands and asked for proof of impact for excavation activities; however, other suits are pending. To combat wetland destruction, many states have individually closed this loophole by passing regulations on a statewide level protecting isolated wetlands and waters of the United States.

A recent court ruling in *Rampanos v. United States* further defined the Corps jurisdiction over nontidal wetlands adjacent to nonnavigable waters. The Supreme Court was split, with Justice Anthony Kennedy handing down a ruling that required a "significant nexus" to navigable waters. This ruling and additional state rulings afterward held that in order for a wetland or other nontidal water body to qualify as falling under "federal jurisdiction," it had to have "significant nexus" to navigable waters or be adjacent to navigable waters with a continuous surface connection. On June 5, 2007, the EPA and the Corps jointly issued a guidance memo to their field members. A summary of the key points contained in the memo is included in Figure 15.1.

This memo has substantially increased the documentation required to assert jurisdiction, as well as the time frame for obtaining written verification from these agencies. A Corps Jurisdictional Determination (JD) processing time of one to two months from submittal of the wetland data and detailed investigation has now expanded to a four- to six-month process, if EPA review is required. When planning a project that involves potential wetland areas, this additional time should be accounted for in the schedule.

Wetlands and waters of the United States have historically been looked on as in conflict with development and property rights. However, coastal flooding and erosion as well as water quality issues associated with drinking water supplies have increased public awareness of the critical role that wetlands play in protecting the environment and natural resources critical to the built environment.

Wetlands Defined

Wetlands, as defined by the U.S. Army Corps of Engineers, means "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas" (33 CFR Part 328.3b).

Wetlands represent a varied resource with many names, usually associated with the prevalent vegetation. When wetlands share the same type of vegetation, they can take the same name. For example, forested wetlands can be called swamps and those dominated by grasses are marshes. No two wetlands have identical plant species diversity or the same hydrologic and soil conditions. Generally, what all wetlands have in common is soil saturation or inundation for extended periods (i.e., wetland hydrology) and vegetation adapted to these soil conditions (i.e., hydrophytic vegetation).

Summary of Key Points

The agencies will assert jurisdiction over the following waters:

- Traditional navigable waters
- Wetlands adjacent to traditional navigable waters
- Nonnavigable tributaries of traditional navigable waters that are relatively permanent where the tributaries typically flow year-round or have continuous flow at least seasonally (e.g., typically three months)
- Wetlands that directly abut such tributaries

The agencies will decide jurisdiction over the following waters based on a fact-specific analysis to determine whether they have a significant nexus with a traditional navigable water:

- Nonnavigable tributaries that are not relatively permanent
- Wetlands adjacent to nonnavigable tributaries that are not relatively permanent
- Wetlands adjacent to but that do not directly abut a relatively permanent nonnavigable tributary

The agencies generally will not assert jurisdiction over the following features:

- Swales or erosional features (e.g., gullies, small washes characterized by low-volume, infrequent, or short-duration flow)
- Ditches (including roadside ditches) excavated wholly in and draining only uplands and that do not carry a relatively permanent flow of water

The agencies will apply the significant nexus standard as follows:

- A significant nexus analysis will assess the flow characteristics and functions of the tributary itself and the functions performed by all wetlands adjacent to the tributary to determine if they significantly affect the chemical, physical, and biological integrity of downstream traditional navigable waters.
- Significant nexus includes consideration of hydrologic and ecologic factors.

FIGURE 15.1 Guidance memorandum regarding jurisdictional authority for wetlands.

The most commonly encountered classification system of wetlands was developed by the U.S. Fish and Wildlife Service (FWS) *Classification of Wetlands and Deepwater Habitats of the United States* (Cowardin, et al., 1979). The structure of this classification is hierarchical, and includes five systems further defined by subsystems, classes, subclasses, dominance types, and modifiers. The palustrine system includes all nontidal wetlands dominated by trees, shrubs, persistent emergent, emergent mosses or lichens, and all tidal wetlands where salinity is less than 0.5 percent. Classes under the palustrine system describe the most common vegetative categories, including emergent, scrub-shrub, and forested wetlands. These vegetative classes are further defined by subclasses that describe the dominant type of vegetation, examples of which are listed in Table 15.1.

Wetlands can also be assigned modifiers that describe the water regime or hydrologic conditions of the area, water chemistry, soils, and other special conditions (see Table 15.2).

As can be seen, the use of such a system allows for a fairly detailed description of a particular wetland area. In addition, the use of such familiar terms as *marsh, bog,* and *swamp* may mean different things in different regions of the country. The use of the FWS system not only describes a particular wetland more completely, but also reduces confusion between different regional interpretations.

Wetlands are located somewhere along a natural wetness continuum that exists on the landscape. Locating the boundary between wetlands and uplands (nonwetland areas) on this continuum is the objective of wetland delineation manuals. The definition of what constitutes a jurisdictional wetland has proven controversial (as seen in the regulatory discussion that follows), with many versions of a single delineation manual generated with the full complement of federal agencies contributing; however, for one reason or another, the currently accepted version of the manual is the *U.S. Army Corps of Engineers Wetlands Delineation Manual* (Environmental Laboratory, 1987).

Wetland Functions

After a long history of wetland destruction, wetlands are increasingly recognized as providing desirable functions to society. Today, wetlands are known to act as chemical sinks or transformers that can improve water quality. They act as "kidneys of the landscape" (Mitsch and Gosselink, 1986) by removing excess nutrients in rivers and streams. At the same time, wetlands reduce flooding by desynchronizing flood flows in drainage basins. This is done by detaining stormwaters and releasing them slowly into streams, thereby reducing peak flows. When located along streams and bays, wetlands can buffer erosive forces and hold sediments, thereby preventing loss of shoreline. Wetlands can recharge

TABLE 15.1 Classification Hierarchy of the Palustrine System Showing Class, Subclass, and an Example of Dominant Vegetation

PALUSTRINE SYSTEM

Class	Subclass	Example
Emergent	Persistent	Cattail, cordgrass
	Nonpersistent	Pickerelweed
Scrub-shrub	Broad-leaved deciduous	Alder, buttonbush
	Needle-leaved deciduous	Tamarack (sapling)
	Broad-leaved evergreen	Inkberry, bog laurel
	Needle-leaved evergreen	Pond pine (sapling)
Forested	Broad-leaved deciduous	Red maple, tupelo gum
	Needle-leaved deciduous	Bald cypress
	Broad-leaved evergreen	Sweet bay, mangroves
	Needle-leaved evergreen	Northern white cedar

From Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. *Classifications of Wetlands and Deepwater Habitats of the United States.* Washington, D.C.: U.S. Fish and Wildlife Service.

TABLE 15.2 Modifiers to Be Applied at Class Level and Lower in the Classification Hierarchy

Modifier		Example
Water regime	Nontidal	Permanently flooded
		Intermittently exposed
		Semipermanently flooded
		Seasonally flooded
		Saturated
		Temporarily flooded
		Intermittently flooded
		Artificially flooded
Water chemistry	Salinity	Saline
		Mixosaline
	pH	Acid
		Circumneutral
		Alkaline
Soils		Mineral
		Organic
Special		Excavated
		Impounded
		Diked
		Partly drained
		Farmed

From Cowardin, L.M., V. Carter, F.C. Golet, and E.T. Laroe. 1979. *Classifications of Wetlands and Deepwater Habitats of the United States.* Washington, D.C.: U.S. Fish and Wildlife Service.

or discharge aquifers, depending on their topographical position on the landscape. Therefore a wetland may either replenish the aquifer or contribute to base flow in streams.

Water Quality. As water purifiers, wetlands act to reduce nutrients, chemical wastes, and turbidity. Wetland plants remove nutrients such as phosphorus and nitrogen from surface waters and utilize them for growth. Removing the nutrients from surface waters not only prevents algal blooms but also reduces the potential for fish kill by preventing the decreases in dissolved oxygen levels caused by the decomposing algal masses. A wetland's ability to absorb nutrients varies between individual wetlands and wetland types. Furthermore, a wetland can be overloaded with nutrients and thus be unable to assimilate the entire nutrient load.

The effective removal of those nutrients has been demonstrated on numerous projects by allowing nutrient-laden effluent (i.e., sewage or wastewater) to flow through wetlands. Organic compounds are decomposed, and nitrogen is converted to its gaseous form and removed (Mitsch and Gosselink, 1986). Heavy metals adsorbed to sediments are allowed to settle out in the diffuse and low-velocity environment of a wetland. As sediments fall out of the water column, turbidity is reduced, allowing sunlight to penetrate to support growth of submerged aquatic vegetation (SAV).

Fish and Wildlife Habitat. Wetlands are among the most productive ecosystems in the world in terms of photosynthetically producing energy from the sun and recycling nutrients. They provide food and habitat for an array of wildlife and are critical in the nesting, migration, and wintering of waterfowl. Although wetlands are not a high percentage of our total land area, they are critical to the life history of over one-third of our nation's threatened and endangered plant and animal species. Coastal wetlands provide spawning habitat, as well as nursery and feeding areas, for much of our commercially important fish and shellfish. Additionally, wetlands are critical feeding, resting, breeding, and nesting areas for migratory waterfowl (EPA, 1995).

As an example, consider the role of SAV in an estuary such as the Chesapeake Bay. Historically, vast numbers of waterfowl (primarily redhead and canvasback ducks) wintered in the freshwater areas of the bay, where wild celery beds were abundant. Declines in SAV in the bay and its rivers have led to a decline in the number of canvasbacks and redheads overwintering in the area. In addition, commercially important fish species such as striped bass, shad, and menhaden are dependent on the bay's SAV for spawning, feeding, and nursery habitat. Though likely not the sole reason for their diminished numbers, as SAV declined in the bay, the commercial and sport fishery for striped bass was reduced to the point where all fishing for the species was banned for several years in the 1980s.

Effects on Flooding. Wetlands within a watershed can reduce flood flows along streams through the detention of floodwaters during a storm. The relative ability of a wetland to alter flood flows depends on several variables including its size relative to the size of the watershed, its relationship to other wetlands in the watershed, and the amount of urbanization in the watershed. In many respects, wetlands serve as a natural form of stormwater management. Coastal wetlands provide similar benefits in terms of reducing the potential flood damages associated with tropical storms, hurricanes, northeasters, and the like. The wetland vegetation dissipates wave energy, thus reducing potential wave heights and storm surge, while coastal wetlands such as barrier islands serve as a buffer to protect shoreline areas from wave-induced erosion.

Recreation. In addition to commercially important fish and shellfish that depend on wetlands for all or part of their life cycle, many of the species pursued by sport fishermen are spawned or reared in our coastal wetlands. Hunting, especially for waterfowl, is very popular and generates substantial benefits to local economies. Waterfowl hunters spend over $2.3 billion in total economic output annually including guns, ammunition, lodging, guides, boats, decoys, and other equipment in pursuit of their quarry (Henderson, 2005). In addition to consumptive uses like hunting, fishing, and trapping, many individuals spend a great deal of time (and money) on nonconsumptive uses such as birdwatching, hiking, photography, and canoeing in wetlands. According to the EPA, more than 98 million people take part in these recreational activities associated with wetlands and spend approximately $59.5 billion annually.

Wetland Losses

More than 50 percent of the wetlands in the continental United States have been destroyed in the last 200 years, according to the U.S. Fish and Wildlife Service. In other words, by 1997, of the approximately 220 million acres that existed in the 1600s only about 105.5 million acres remained. Between the mid-1950s and mid-1970s, there was an increase in wetland losses per year with a net loss of 9 million acres of wetland (USEPA, 1995). Drainage of wetlands for agriculture was responsible for 85 percent of losses, with development causing approximately 13 percent of the losses. Most losses due to agriculture occurred in the Lower Mississippi Valley and in the Prairie Pothole Region of the Upper Midwest. Bottomland hardwood forests and marshes, respectively, were affected in these regions.

The loss of wetlands from urban and suburban development was greatest in coastal states. Over 90 percent of the wetlands in California have been drained for agriculture or filled for development since initial settlement. Over two-thirds of wetland losses in Delaware between the mid-1950s and mid-1970s (Tiner, 1984) were attributable to development.

Between 1986 and 1997, there was a reduction in the annual loss rate to approximately 58,500 acres of wetland losses per year. This was a 50 percent reduction in the average annual rate from the mid 1970s to the mid 1980s. The reduction in wetland losses experienced during this time can be attributed largely to implementation and enforcement of wetland protection laws and regulations, public outreach and education about the value of wetlands as a natural resource, wetland creation and restoration efforts, and coastal zone monitoring (Dahl, 2006).

The most recent report from the U.S. Fisheries and Wildlife Service, *Status and Trends of Wetlands in the Conterminous United States from 1998 to 2004,* showed, for the first time, a net wetland gain of 191,750 acres. This report goes on to point out that the gains would not have occurred without the substantial increase in open-water ponds, of some 700,000 acres. There was actually a decrease in estuarine vegetated wetlands of 32,400 acres (due to a conversion to open-water ponds) and freshwater emergent and shrub wetlands declined by 142,570 acres. Forested wetlands did increase from shrub conversion by 548,200 acres.

The *Status and Trends* report also states that “ponds created as mitigation for the loss of some vegetated wetlands types are not an equivalent replacement for those wetlands.” This is an important consideration when determining mitigation possibilities for a development project.

Wetland Delineation Criteria and Methodology

The methodology for determining the presence of a wetland is based on three elements: soils, vegetation, and hydrology. For an area to be identified as a jurisdictional wetland, the area must contain these three wetland parameters: hydric soils, hydrophytic vegetation, and wetland hydrology, or evidence thereof in disturbed areas. Field indicators of the three-wetland criteria are provided in the various available delineation manuals. When field indicators of each of the criteria are observed, the area is determined to be a wetland.

Soils. Hydric soils are defined as “soils that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part of the soil” (*Federal Register,* July 13, 1994). These soils are typically recognized in the field by observing soil color and comparing it to the Munsell Soil Color Charts (Munsell Color, 2000, rev. ed.). The color of a soil is described with three variables: hue, value, and chroma. The hue variable is used to relate the color of the soil as red, yellow, green, blue, or purple. The value indicates the color’s degree of lightness, and the chroma is its strength. In the Munsell Soil Color Charts book, each hue has its own page. Value and chroma are shown on the vertical and horizontal axes, respectively, of each page. A numeric scale on each axis increases with increasing value (lightness) and increasing chroma (strength). See Figure 15.2.

Indicators of hydric soils form by the accumulation or loss of compounds such as iron manganese, sulfur, or carbon. Typically, mineral soils, like those found in the eastern United States, subjected to prolonged saturation or inundation, express the condition as gleization and mottling. Gleization is seen as a predominant neutral gray to sometimes greenish or bluish gray color (low chroma) in the upper part of the soil profile. Reduced compounds are easily leached from the soil under saturated anaerobic conditions, and the low chroma indicates an absence of iron. Mottling represents incomplete reduction of the soil’s iron and is seen in the upper part of the profile as mosaics of brown or red oxidized soil interspersed with low-chroma reduced areas. Typically, the grayer or more gleyed the soil is, the longer the duration of soil inundation or saturation periods. The dominant color of the soil (more than 50 percent) is called the *matrix,* and the remainder, *mottles.* In most cases, when the matrix has a chroma of 2 or less with mottles present, or 1 or less without mottles, the soil is hydric.

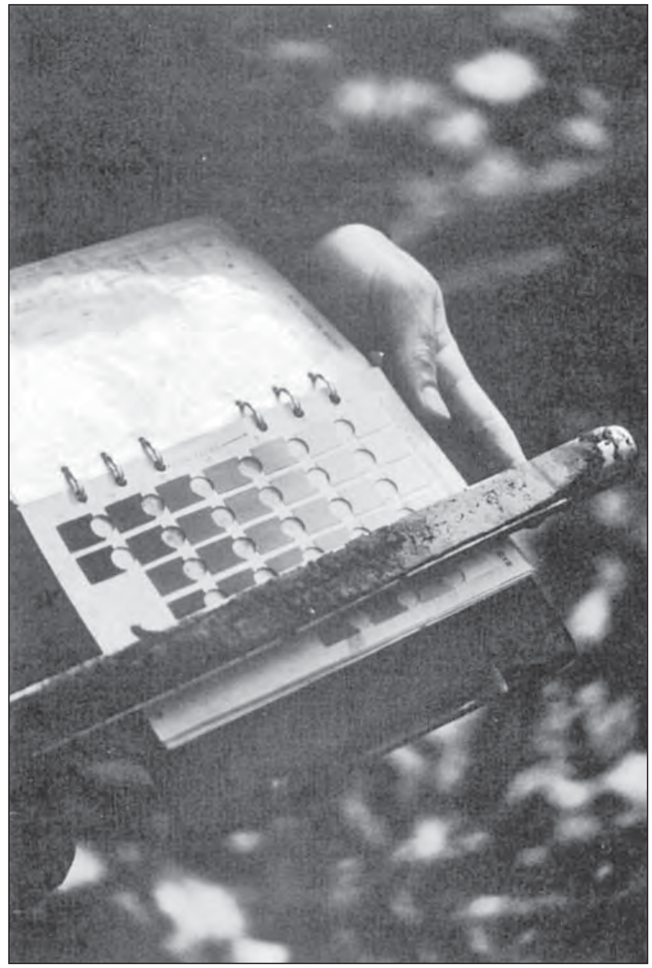

FIGURE 15.2 A gleyed hydric soil sample being compared to the Munsell Soil Color Chart.

Organic hydric soils are largely an accumulation of nondecomposed, organic remains (peat). These soils are easily recognized as hydric soil by a thick organic surface layer that is saturated for most of the year.

In some problem soils, such as sandy soils and soils derived from red parent material, the gleization may not be exhibited due to the extremely low (sandy) or extremely high natural concentration of iron. Wetland identification in these problem-area soils may take slightly longer to identify in the field and may require detail beyond the scope of this chapter.

TABLE 15.3 Indicator Categories Showing the Estimated Probability of a Species Occurring in Wetlands vs. Nonwetlands

INDICATOR STATUS	PROBABILITY OF OCCURRING IN WETLANDS
Obligate wetland (OBL)	>99%
Facultative wetland (FACW)	67–99%
Facultative (FAC)	34–66%
Facultative upland (FACU)	1–33%
Upland (UPL)	<1%

Vegetation. Hydrophytic vegetation is defined as plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content (Environmental Laboratory, 1987). Many plants have adapted to these conditions to create the great diversity of plants found in wetland environments. About 7000 plant species are included on the Fish and Wildlife Service's *National List of Plant Species That Occur in Wetlands: 1988* (Reed, 1988). This list provides habitat information and a wetland indicator for each species. The wetland indicator is an estimate of the probability that a species will occur in wetland versus nonwetland areas. A hydrophytic vegetation determination is based on the wetland indicator status of all dominant plant species in an area. The indicator status can be determined online through the Natural Resource Conservation Service's website at http://plants.usda.gov/wetland.html. Under the current *Corps of Engineers Wetlands Delineation Manual,* more than 50 percent of the dominant species must have an indicator status of OBL, FACW, or FAC for an area to meet the hydrophytic vegetation criterion. This status indicates the frequency of occurrence of a species in wetlands, as shown in Table 15.3

Hydrology. The hydrology of a wetland is the most important element that defines the wetland type and function. Water that creates wetlands comes from several sources including ground water discharge, out-of-bank stream flow (flooding), surface runoff of precipitation or snowmelt, direct precipitation, or tidal flooding. The roles of ground water and surface water in creating wetlands are illustrated in Figure 15.3. As expressed in the figure, wetlands are typically located between the seldom-flooded upland and perennial waters of creeks, rivers, and bays.

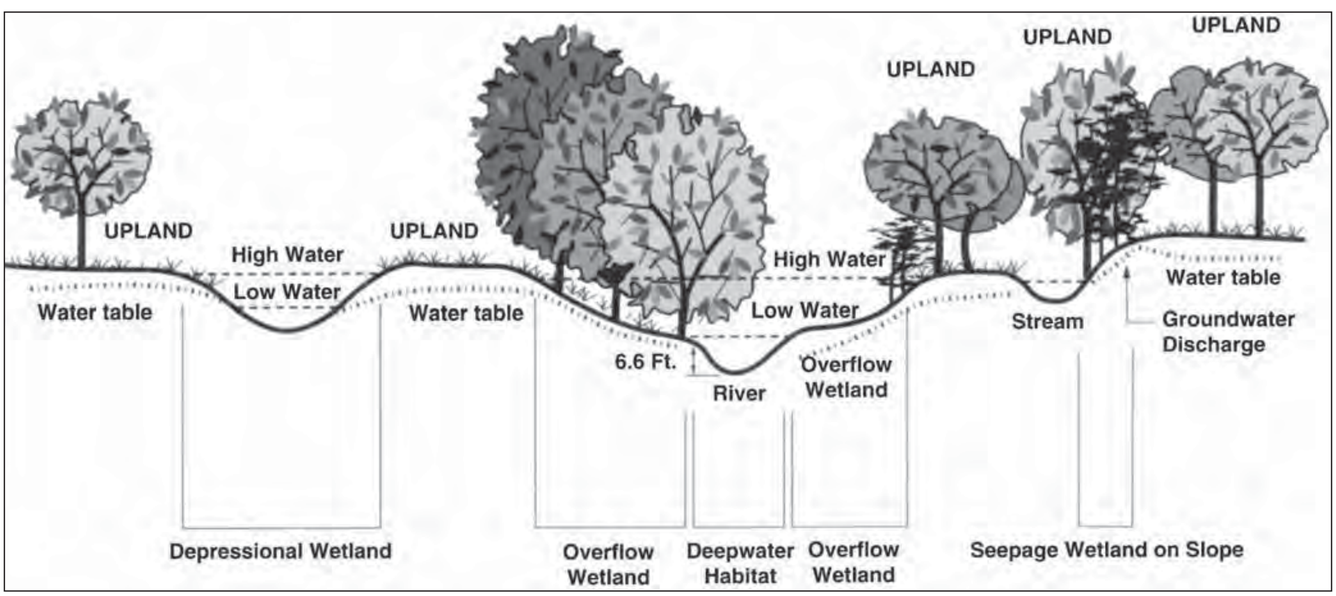

FIGURE 15.3 Schematic diagram showing wetlands, deep-water habitats, and uplands on landscape. (Adapted from Tiner, 1984; U.S. Fish and Wildlife Service)

The presence or absence of wetland hydrology is determined using recorded data and field indicators. Recorded hydrologic data, such as stream, lake, or tidal gauge records can provide information on the duration of flooding in areas adjacent to the water body. In ground water-driven wetlands, the county soil survey can be useful in determining duration of soil saturation.

Wetland hydrology in the form of surface water or saturated soils is readily apparent during certain times of the year in most wetlands and in other types of wetlands during most of the year (Federal Interagency Committee for Wetland Delineation, 1989). Evidence of this could be standing surface water or muddy ground surface underfoot; however, during certain times of the year—primarily late spring to early fall or during drought events—when surface water isn't evident, wetland hydrology may not be as obvious. These types of wetlands are simple to identify in agricultural lands, as they contain the few uncultivated areas where the tractor might get stuck or which can only be cultivated late in the season. For these reasons, secondary field indicators may be used to confirm the presence of wetland hydrology when hydrophytic vegetation and hydric soil are determined to be present. Field indicators of hydrology listed in the Corps manual include the following:

- Visual observation of inundation or saturation
- Watermarks indicating prior inundation
- Driftlines of water-carried debris
- Sediment deposits
- Drainage patterns within wetlands
- Oxidized rhizospheres

An example of obvious wetland hydrology is shown in Figure 15.4, a wetland created by a beaver dam. A much less obvious wetland, created by ground water discharge is shown in Figure 15.5.

FIGURE 15.4 A wetland created by a beaver dam built on a stream channel.

FIGURE 15.5 A palustrine emergent wetland created by ground water discharge at the surface.

Field Delineation. In the field, wetlands professionals utilize the approved *U.S. Army Corps of Engineers Wetland Delineation Manual* to evaluate the three primary characteristics of a wetland. The current Corps delineation methodology requires positive indicators of all three wetland criteria (soils, hydrophytic vegetation, and hydrology) to delineate an area as wetland. The wetland-upland boundary is determined where one or more of the criteria fall out. The only exception to this is the situation where one or more of the criteria are not present due to a disturbance to the area. A common example of a disturbed condition is the situation where hydrophytic vegetation is not present because of farming activities that have temporarily replaced the natural vegetation with planted crops or pasture.

Wetland hydrology, generally the most difficult of the three criteria to verify in the field, is normally confirmed through the use of field indicators, as previously described. However, during prolonged drought, the Corps may require the placement of surface water monitoring wells and monitoring under "normal conditions" to verify a presence or lack of hydrology. Other than a direct indicator of water, evidence of hydrology can be supported by the presence of hydric soils. As noted previously, all three parameters must be present for the site to be determined a wetland.

A wetland delineation is usually completed in two stages: the preliminary investigation, often performed concurrently with the Environmental Feasibility and Site Assessment to determine whether wetlands exist and their approximate limits, and the detailed investigation where the jurisdictional area for preliminarily identified wetlands or waters of the United States is accurately identified based on an enhanced level of data collection and field review. The accuracy of a preliminary wetlands investigation is lessened when the topographic relief is low and the wetland is not confined to distinct stream valleys. A lack of landmarks in areas of low relief also limits the accuracy of the preliminary study because sketching the wetland boundary in the field is an approximation and landmarks aid in placing the wetlands/uplands boundary correctly. All of these factors influence the confidence level of the preliminary wetlands study and necessitate a more formal, detailed investigation for accurate delineation.

Detailed Wetland Investigation. A detailed wetland investigation offers the most accurate delineation and measurement of the jurisdictional areas on the site. This level of effort is necessary when the confidence level of the preliminary study is not sufficient or the exact location of the boundary and/or total wetland acreage must be defined for permitting purposes. A jurisdictional boundary needs to be accurately depicted when designing a project to assist in th avoidance and minimization of impacts during the early stages of design.

The accurate acreage of impacts will be used to confidently determine permit eligibility (discussed in the following section). Furthermore, if wetland or waters mitigation is a requirement of the permit conditions, precise jurisdictional acreage is important due to the high cost of wetland mitigation.

A detailed investigation requires a much more intensive sampling effort, with more sampling points. The boundary is then flagged with surveyors ribbon and located by field survey. This survey is then overlain on the proposed site plan (schematic-level plans or up to 60 percent design) to determine impacts to jurisdictional areas and identify potential avoidance and minimization strategies to assist in obtaining the necessary regulatory permits. The ins and outs of regulatory permitting are discussed in detail in Chapter 31.

As stated in Chapter 3, all properties slated for development should be reviewed to determine whether they contain wetlands or waters of the United States. If the initial site feasibility report indicated that the site might contain wetlands, it would be prudent to hire an experienced or certified professional to conduct a wetland delineation. Due to the variability of regional conditions, it is advisable to engage environmental professionals familiar with the region who also have a rapport with the local regulatory authorities.

Wetlands and the Site Development Process. Once on-site wetlands and waters of the United States have been accurately mapped, they can be overlaid on the development program envisioned. At this point it is not uncommon for vision and reality to conflict; schematic-level design is intended to resolve this exact conflict by refining the design and development program with respect to newly obtained and more accurate mapping.

In order to obtain permits to impact wetlands, the project must demonstrate a process of avoidance, minimization, and, ultimately, mitigation for impacts that are unavoidable. All reasoning for not avoiding or minimizing must be backed up with defensible justification, including costs. Costs detrimental to the development (i.e., lost buildable area) must be balanced with costs of mitigation and the consequences of the impacts. If wetlands and waters are present on-site, the final delineation may reduce the number of buildable lots or area originally envisioned.

Wetland mitigation costs vary from region to region and are normally a product of the cost of the land. In 2007, in the Washington, D.C., area, 1 acre of wetland credit cost \$125,000 to \$150,000 and stream mitigation cost roughly \$400 to \$800 per linear foot (this includes both perennial and intermittent stream credits). It should also be noted that if the project impacts a forested wetland, mitigation is normally required at a 2:1 ratio. If a project is expected to impact a high-quality stream as determined by the environmental professional utilizing the approved stream assessment methodology for the physiographic region, the mitigation credit ratio could also be higher than 1:1. Overall costs should be considered; for example, a stream crossing utilizing a triple cell box culvert directly impacts the stream and requires mitigation. A precast concrete bridge, which does not impact the stream directly, is equal in cost when factoring in the mitigation cost associated with the stream impact from the culvert and greatly assists in obtaining the requisite permits in a timely fashion due to the reduced nature of the impacts.

In terms of land development projects, the best avoidance strategy is informed site planning: utilize layouts where roadways and lots are located in the uplands and stream valley corridors are at the back of lots. Many homeowners and planners find this type of buffer highly desirable for aesthetics as well as recreation.

OPEN-SPACE AND VEGETATION PRESERVATION

> *Tree protection in land development should be a shared community responsibility. Developers need to approach their projects with some environmental sensitivity. Citizens need to understand the needs of developers. And local governments must be flexible, yet recognize and support the need for tree protection and replacement. If all three sectors cooperate, our cities can grow while remaining beautiful and environmentally healthy.* (Macie and Moll, 1989)

Open-space preservation, in many cases, is not limited to the preservation of individual trees; rather, it generally implies preservation of existing trees and other associated vegetation, including the understory trees, shrubs, vines, and herbaceous plants. Preservation in this manner and at a reasonable scale (i.e., in contiguous areas or connected in an open-space or greenway corridor) maintains the value and function of the resource. Within the context of green building and sustainable design, open space is prioritized even at the very localized (site) level in order to protect/restore habitat, promote biodiversity, and expand opportunities for interacting positively with the environment.

The Values and Benefits of Trees and Open Space

Understanding the significance of open space and especially tree preservation requires a basic understanding of the values and benefits provided by landscape elements and green space or open space in general. Figure 15.6 illustrates the functional uses of plant material, from which the following values and benefits are derived:

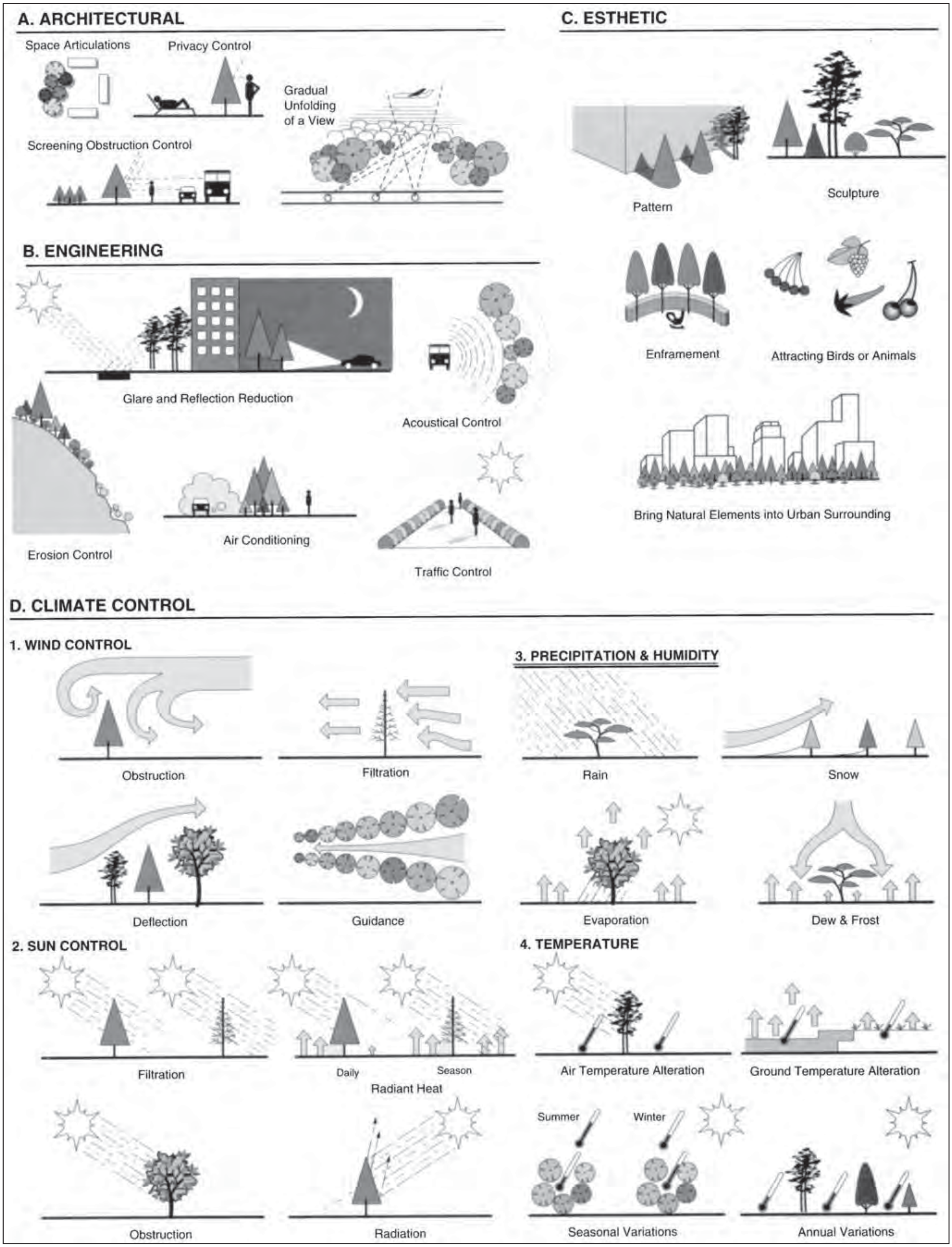

FIGURE 15.6 Functional uses of plant material that have measurable value and benefits. (From Neely, Dan. 1982. *Guide to Plant Appraisal,* 8th ed. International Society of Arboriculture)

- Aesthetics
- Space definition and articulation
- Screening undesirable views
- Complementing or softening architecture
- Creating a sense of unity among inharmonious buildings
- Providing textural and pattern variety
- Buffering incompatible land uses
- Attracting wildlife

Trees affect the microclimate of an area by moderating the effects of sun, wind, temperature, and precipitation. Such climatological values and benefits include:

- Intercepting, filtering, or blocking unwanted solar radiation
- Blocking undesirable wind by obstruction
- Directing wind flow by deflection
- Reducing wind velocities by filtration
- Moderating temperature changes (although this is more directly a function of solar radiation interception)

The value and benefits of trees and open space relative to site development and engineering are equally as important. These include:

- Decreasing stormwater runoff directly through interception of rainfall and water uptake through the root system, as well as filtering pollutants contained in runoff from the adjacent watershed
- Stabilization of soils
- Reducing the glare and reflection characteristically generated by the combination of buildings and/or roadways and natural and/or artificial light
- Acting as noise attenuators
- Interacting with the particulate matter and gasses known to cause air pollution to significantly reduce the concentrations of these pollutants
- Adding extra oxygen to the atmosphere
- Recreational opportunities (gardening, ballfields, hiking trails)
- Education
- Nonpolluting transportation (bike trails)
- Tourism
- Flood protection

All of the architectural, aesthetic, climatological, and engineering uses give value to trees that can be described in both economic and legal terms (Miller, 1988). Because of these measurable assets, trees and open space contribute to and enhance property values. The resulting sum of values equates to an improvement in the quality of life for everyone. This concept is emphasized in the green building rating systems whereby credits are commonly awarded for habitat preservation/creation and open-space optimization.

Preservation/Protection Ordinances

Open spaces are considered valuable environmental resources, and the incremental but steady loss of these resources has prompted many jurisdictions to enact legislation to preserve and protect riparian corridors, forested areas, farmlands, and unique natural resources such as prairies, meadows, and deserts, as well as individual trees. In addition, increasingly poor water quality and urbanization in areas that were once very rural have led communities to protect not only the natural resources, but entire watersheds and viewsheds as well. This legislation is generally enforced through local zoning or landscape ordinances. Many of these ordinances have been created to act as guides for responsible or appropriate land development activities so that the preservation of the resource is balanced with site development. These ordinances and regulations are generally not intended to prohibit development activity, merely to cultivate a balance between the natural and built environment that is beneficial to all those participating in the development process. Land development and preservation need not be mutually exclusive. In fact, open-space preservation has been demonstrated to prevent flood damage, attract investment, revitalize cities, and boost tourism along with preserving the environment (Lerner and Poole, 1999).

Since communities differ in their natural environment, political structures, cultural traditions, and legal framework, preservation ordinances vary between jurisdictions. However, all jurisdictions have similar goals of protecting natural and cultural resources, historic views, and floodplains. These ordinances and regulations are specific to the local community desires and economic needs.

Regulations within preservation ordinances may also vary widely among jurisdictions. Some localities are quite specific about the percentage of existing vegetation that must be retained and have designed methodologies for determining the extent of existing vegetation to be targeted for retention. Other localities simply offer general guidelines requiring that all attempts possible be made to retain existing vegetation. Most ordinances establish the definitions, procedures, penalties, and appeals process specific to the individual locality for preservation and protection. In some instances, preservation ordinances are developed to protect entire ecosystems, such as those areas that are known habitats of rare, threatened, or endangered species, or watersheds that drain into a public water supply.

Since variation among ordinances can be great, and all ordinances are specifically reflective of the local policies, circumstances, and needs of a particular area, it is more critical here to understand the general basic premise for an ordinance, rather than the details specific to many localities. Specific preservation ordinances exist in a majority of the towns, cities, and urbanized areas nationwide, and they may be separate or included as part of larger ordinances. It is the responsibility of the site designer (or design team) to be cognizant of the requirements particular to the jurisdiction in which a specific project is located.

Green Building Requirements. As jurisdictions continue to adopt green building ordinances or to "strongly recommend" green building practices through their comprehensive plans and other regulatory language, it is often important for land development consultants to consider open-space and landscaping decisions earlier in the design process and to resolve or design them as a separate infrastructure component subject to the same level of increasing detail afforded to roads, utilities, and grading.

As noted, many of the green building rating systems include open-space preservation/restoration as a component part of the site development section. First and foremost through *avoidance,* the rating systems encourage the selection of a site or placement of site development outside environmentally sensitive areas. With specific reference to USGBC's LEED-NC standard (as discussed and carried throughout this text), Sustainable Sites (SS) credits 1, 5.1, and 5.2 speak directly to appropriate site selection, protecting and restoring habitat, and maximizing open space. The specific requirements are as follows:

- 1—Site Selection: Awarded to sites that are *not* located on prime farmland, parkland, endangered species habitat, within 5 feet of the 100-year flood elevation, within 100 feet of wetlands or wetland setbacks, or within 50 feet of a water body regulated under the Clean Water Act.

- 5.1—Protect and Restore Habitat: There are two compliance paths, the applicable one being based on the type of project. Greenfield (new development) projects must adhere to strict limits of clearing and grading: 40 feet beyond the building footprint, 10 feet beyond impervious surfaces and utilities under 12 inches in diameter, 15 feet beyond roads and main utility trenches, and 25 feet beyond constructed areas with permeable surfaces such as stormwater management (SWM) facilities. Redevelopment projects must restore 50 percent of the site area, excluding the building footprint, with native or adaptive vegetation.

- 5.2—Maximize Open Space: There are three compliance paths, the applicable one being based on the locality's zoning ordinance and/or open-space requirements. If the locality specifies an open-space requirement, the project should exceed that requirement by 25 percent. For projects with no zoning requirements (i.e., certain government facilities, military bases, or campus projects), vegetated open space equivalent to the building footprint should be provided adjacent to the building. If the locality has a zoning ordinance but no open-space requirement, the project should provide open space equal to 20 percent of the site area.

This combination of credits related to open space and natural resource preservation emphasizes the front-end importance of decisions related to site selection and appropriate consideration of environmental and natural resources from the start of the project throughout the design and development process. If these open-space credits are designated as achievable or target credits during the initial goal-setting process, it is important at this stage of the schematic-level design to ensure the project is on track: identify the limits of clearing and grading and ensure the engineer developing the erosion and sediment (E&S) plan and construction sequence is aware of these limits, discuss a native vegetation and planting plan with the landscape architect, and work with the planner/engineer/designer to refine the open-space areas and check against the appropriate compliance path. These credits are intended to be attainable for any site whether rural, suburban, or urban; a LEED AP or other consultant familiar with green building practices can help the design team assess the project open-space scenario and apply caveats—such as the use of greenroofs or pedestrian hardscape (rather untraditional forms of open space)—to meet open-space requirements and attain specific project green building goals.

Open Space, Tree Preservation, and the Site Development Process

It is critical to understand that in order for open-space and tree preservation to be successful, it must be integrated into the early planning stages of land development. It is nearly an impossible task to address these types of preservation issues later in the site design stages while still achieving the optimum balance between the built and the natural environments. Making the most of portions of the property not conducive to traditional development is contingent on early consideration of these spaces. Retrofitted open-space and tree preservation has a greater chance of failure and can actually create unwanted liabilities and costs. Properly planned and implemented open-space and tree preservation can enhance the aesthetic, natural, and economic environments for all.

Preservation is best accomplished during the early planning or feasibility phase of site development, as part of the site inventory and analysis. To ensure the success of any preservation program, the tasks associated with the formulation of the preservation plans should be completed by a professional knowledgeable in the topics of biology, physiology, taxonomy, and ecology, as well as the relationship between those ecosystem functions and land development. Many methodologies exist for determining the quality of trees or other natural resources, and all have a common goal of identifying the high-quality habitats existing on a particular site. The following discussion addresses the basics applicable to most methods of vegetation analysis and preservation. Again, familiarity with regulations pertinent to the locality of the site is the responsibility of the site designer or design team.

Prior to any site visit, a review and analysis of the existing site conditions will provide an overview of the limits of the existing vegetation; the site topography; soils locations and descriptions; riparian areas such as streams, ponds, and/or wetlands; open fields; existing buildings; and other existing and/or natural features. These living and nonliving factors influence the species and quality of vegetation indigenous to the site. A review of recent aerial photography of the site not only affords an overview of the site, but allows a characterization of existing vegetative patterns on-site as well.

Existing site information or data collected during a site visit can range from general to detailed, depending on the level of information desired or required regarding the vegetation. At a minimum, the data collected during a site visit should include the following:

- The individual, significant trees and groups of similar trees
- The species present
- The quality of forest structure
- Relative age and condition of species tree stands
- Any riparian areas, local or federal floodplains, and wetlands
- Required setbacks and landscape buffer widths included in local ordinances
- Existing and proposed utility corridors

Other information can include:

- The locations of scenic vistas, important wildlife habitats, or obvious past or present management activity (logging, prescribed burning, etc.)
- Transplantable tree stock
- Obvious insects or diseases present
- Any other natural or cultural feature that may contribute to the significance of the vegetative cover and ambiance of the project or that may require avoidance or vegetative buffers
- Practices and measures taken to assist with future green building certification and the combination of these efforts with permitting/local ordinances whenever possible

The appropriate analysis of this collected data identifies and prioritizes the quality of the existing vegetation and its placement in the landscape. The prioritization of the existing vegetation in turn influences the placement of roads, buildings, parking lots, utilities, and other development program features integrated into the conceptual design of the site. The objective is to place site improvements where there will be a minimal impact on the desirable vegetation targeted for preservation.

As the site design progresses from the conceptual design phase to the schematic design phase, the preservation or conservation plan should be developed concurrently with detail clearing limits, preservation areas or protection zones, and protection techniques, to successfully implement the desired preservation.

The U.S. Army Corps of Engineers regulatory division, as well as many state governments, has placed a recent emphasis on the preservation of vegetative buffers located adjacent to riparian areas (streams, rivers, lakes, etc.), particularly if the buffer area is forested. Riparian forest buffers have been found to have significant benefits to water quality (Klapproth and Johnson, 2000). Planning for the preservation of these riparian buffers, floodplains, and wetlands during the conceptual and schematic design phase may assist with future permitting and is a green building site–related priority.

Ideally, all trees along clearing limits and proximate to construction should be located by survey methods, plotted on a map, and identified by species and diameter size. These individual trees along the clearing limits should be evaluated for their respective health and structural condition, expected longevity, critical root zone areas, potential tolerance to construction activity, the suitability of the species for the new use, and the level of ongoing maintenance (Harris, 1992). This evaluation process will assist in identifying which trees are the best or most appropriate candidates for preservation. Typically, groups of trees are more successfully preserved than individual trees, and younger trees are more tolerant of changes in their environment than older trees.

Forest Preservation, Location, and Function

For the purpose of this discussion, it is important to understand the biological and structural differences between trees growing under different conditions. Trees located in the forest interior have few lower limbs, the root systems must compete with many neighbors for water and nutrients, their crowns spread considerably in competition for sunlight, and their growth is slowly upward toward the light. When site grading removes some of the surrounding trees, previously interior trees are exposed to desiccation from wind and sun, their hydrologic regime is altered (usually becoming drier), and they become subjected to increased insect and disease infestations. These trees will tend to have a spindly appearance and will, over time, sprout numerous short branches. Windthrow can also be a critical problem for these trees because of their top-heavy structure and relatively shallow root systems.

Trees that grow naturally at the edge of a forest function to protect the forest interior. Therefore, their growth pattern tends to be outward, away from competing neighbors, both above and below ground. Most of the branches on edge trees grow outward toward the abundant light with few branches occurring on the shaded side, resulting in a lopsided structure. When site clearing removes trees from the shaded side of edge trees, the trees are subject to increased stresses from the new exposure, increased occurrence of insects and disease, and windthrow. When construction activity alters the existing grade on the open side, these trees suffer considerable root damage, since their roots extend far beyond the canopy dripline and are also subject to windthrow.

Isolated trees have adapted to life in an exposed situation. They do not compete directly with other trees for sunlight, water, and nutrients. Their growth patterns are outward and upward in all directions. Generally, isolated trees have well-rounded crowns and branch in all directions along most of the length of the trunk. Roots of isolated trees generally spread farther from the trunk than do roots of trees growing in competition with each other, expanding to a circumference at least two times the height of the tree.

Tree Protection during Construction

In tree preservation, the root zone area is the critical and limiting factor of success. Plants depend on roots for water and mineral uptake, storage of food reserves, and the synthesis of needed organic compounds and anchorage. Generally, tree roots are located in the upper 36 inches of the soil, with the majority of the roots (85 percent) in the upper 18 inches. However, two factors that can significantly alter that generalization are the soil texture and existing forest litter. The finer the soil texture, the shallower the absorbing tree roots; similarly, the thicker the leaf litter, the shallower the absorbing roots. In many cases, the feeder roots of trees growing in finer-texture soils and/or mature forest situations will occur in the upper 6 to 12 inches of soil (Harris, 1992).

Any land development activity that affects the roots of trees will directly affect the aboveground portions, either proportionately or disproportionately. Recent research has found that tree roots can extend far beyond a tree's dripline, typically branching out from the trunk a distance of 1 to 1.5 times the tree's height (Dicke, MSU, 2004). Healthy roots grow where the soil aeration, moisture, soil temperature, nutrients, and soil structure are favorable.

Unless the tree canopy is physically or chemically damaged in some way, or the trunk or branches are physically or mechanically damaged, most construction-related injury involves root damage. One common form of construction-related tree root damage (Figure 15.7) occurs because of extensive disturbance of the soil peripheral around preservation areas while removing the trees adjacent to the preservation areas (i.e., pulling stumps instead of grinding them). Other damage includes:

- Root severance in the topsoil-stripping process or in lowering grades
- Excavating for footings or trenching for utilities
- Raising the grade, which can suffocate roots
- Compacting the soil, which crushes and suffocates roots
- Changing the hydrologic regime (wetter or drier) by altering existing drainage patterns
- Storing, dumping, or disposing of construction materials that are toxic to plants in or near preservation areas, such as concrete washout areas

For these reasons, tree protection fencing or other protection devices should generally be located outside the critical root zone of the trees that are to be preserved and should be implemented prior to or at the beginning of any clearing and grading activities. The critical root zone is defined by the diameter breast height (dbh) of the tree at 4.5 feet, times 1.25 (Dicke, 2004, MSU); some literature even recommends a multiplier of 1.5.

The tree preservation zones, delineated during the schematic design phase for the site, should be further refined during the conceptual design (preliminary site layout) phase. Often compromises between the site development program and tree preservation zones occur as the proposed site grading is refined. Trees deemed to be severely impacted by the proposed construction should be identified, primarily according to the impacts on the critical root zones, with recommendations for their future disposition. Extensive coordination and communication between the design team and the professional preparing the tree preservation plan are absolutely essential, especially at this stage, because successful integration of the development program and the existing natural environment is dependent on clear and concise communication and coordination.

During Construction and Beyond. Open-space preservation, as with tree and forest preservation, must be incorporated into the early planning process of site development. It can include the preservation of old-field ecosystems, riparian areas of all types, specific geological formations, wetlands, springs, and so on. The preservation of these areas varies widely. Old fields are made up primarily of a mix of perennial flowers, grasses, and what some would classify as weeds. Many wildlife species rely on these old fields for foraging and reproduction; in fact, many songbird species rely strictly on old fields as their primary habitat. Old-field areas are accustomed to some manipulation, such as annual bush hogging, grazing, or fire. Therefore, provided that these areas are not graded, and the seedbank is protected, old fields tend to be more resilient than forested areas during construction activities. However, the long-term development plan for such an area should recognize that some type of manipulation will likely be necessary in the long term to maintain these areas as open fields.

The preservation of unique geological features (caves and the like, as well as natural springs) may require the review and recommendations of a geologist or hydrogeologist to ensure their preservation is made possible after a proposed change in drainage or compaction.

Tree preservation and landscape planting areas must be reviewed in a long-term context to address such issues as future utility conflicts, the consequences of compaction, and

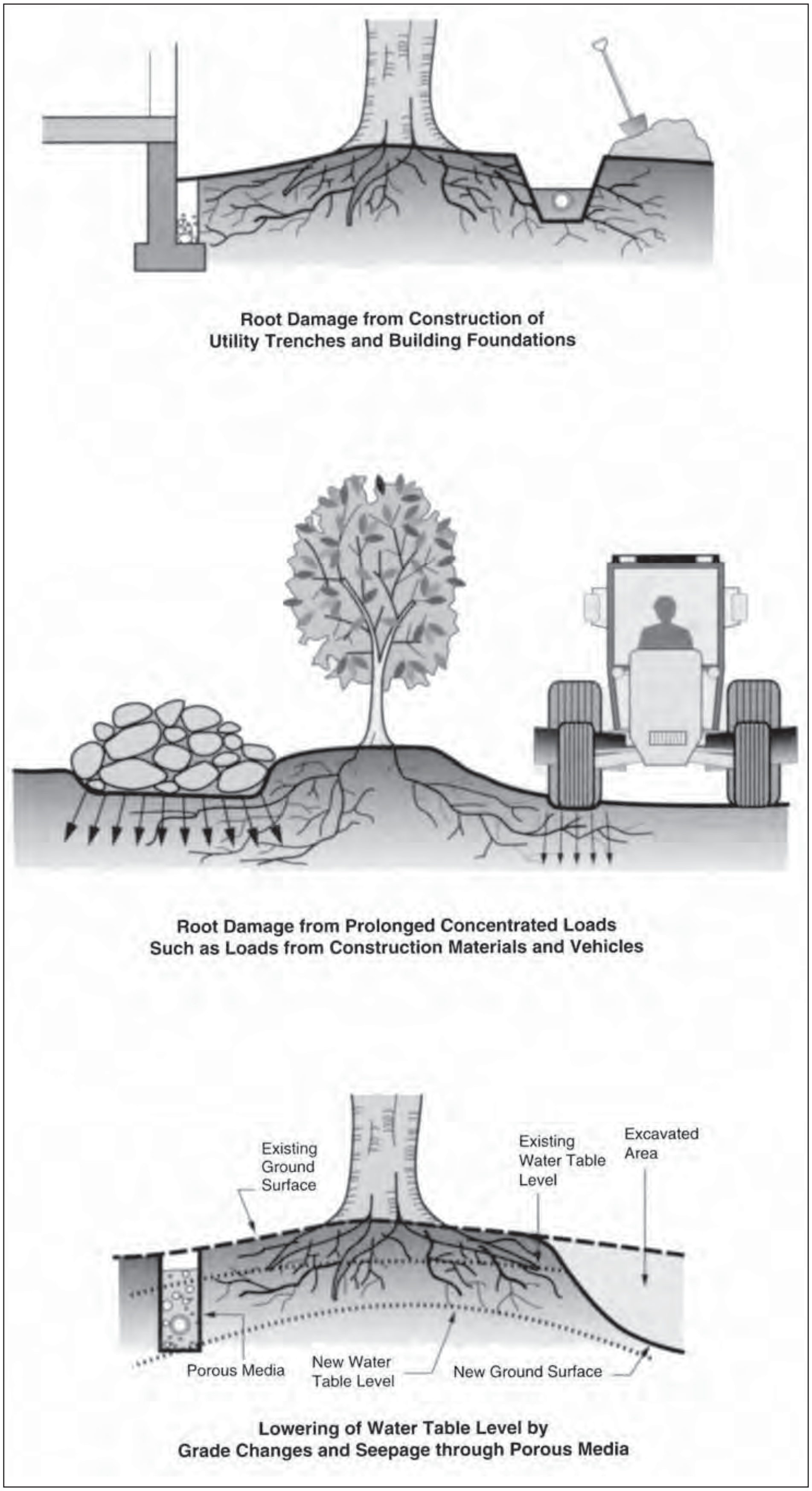

FIGURE 15.7 Construction-related damage to tree roots.

maintenance requirements. When looking at this issue, one must look at both the roots and the canopy. Some species of trees, such as willows and maples, have root systems that eventually find their way into sanitary and storm sewers, while large canopy trees often interfere with overhead utilities. Construction and use impacts to root zones should be reviewed and ameliorated as well. These include root zone compaction from construction or high-foot-traffic areas. A postconstruction plan to aerate, fertilize, and augment the soils around valuable "save trees" and landscape areas should be created to avoid costly mitigation for future die-offs. In addition, landscape trees are expensive; if a project does not include a sprinkler (or other appropriate irrigation) system to maintain these trees, it is a good idea to include watering in the maintenance and replacement contract, and to ensure the maintenance period extends at least 24 months instead of the typical 12. Most large landscape trees do not obtain sufficient root growth to maintain themselves during dry spells within the first year or two of planting.

Open-Space and Tree Preservation Plan

As the site development progresses from the preliminary to the final site layout phase, written detailed recommendations regarding site-specific preservation areas, tree preservation techniques, and remedial care of tree preservation areas are incorporated into the refined preservation plan. The plans and specifications should include a written description and/or graphic depiction of the recommended protection fencing and its location relative to preservation areas, as well as preservation techniques employed to accommodate grade changes (tree wells, retaining walls, spring boxes, drainage, or aeration systems). In addition, the horticultural care of preserved trees, maintenance of open fields, and preservation or treatment of spring boxes should be incorporated into the final plans for all phases of construction including utility installation, preconstruction treatment, and postconstruction maintenance.

Generally, the graphic preservation plan and written specifications are included in the final site plans and become part of the construction permitting process. At this point, it is probable that the coordination of the preservation plan be extended to include the appropriate local reviewing agencies. Larger jurisdictions may have a separate forestry or natural resources staff, who coordinate and comment on these plans, whereas smaller jurisdictions may rely on the forestry and natural resources staff at the state level. Regardless of their size, many jurisdictions now include preservation plans as part of the legal construction documents; therefore, many jurisdictions assess penalties for open-space preservation plan violations just as they would for any other construction violation.

Additionally, many jurisdictions require the inclusion of a long-term protective legal agreement, usually in the form of a recorded conservation agreement, to protect the longevity of preservation areas. These conservation easements place restrictions or conditions on uses within the preservation areas, many of which are permanent, and are recorded as land records.

SUMMARY

Successful preservation requires active, respectful communication among all participants for the duration of the project. This means not only among the professional members of the site development team, but including anyone who will work on the site. For instance, an uninformed contractor, involved in the early stages of site construction, can do unintentional but irreparable damage to prospective preservation areas. However, if the role and contributing value of each participant are effectively communicated, then the project succeeds and all benefit. Tree, open-space, and wetland preservation is no longer incidental to land development, to be treated as an amenity; it has become both economically prudent and environmentally essential.

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CHAPTER 16

IMPACTS TO HISTORIC ARCHITECTURAL AND ARCHAEOLOGICAL RESOURCES

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Updated/Revised: Andrea Burk

INTRODUCTION

Land development is a continual process that reshapes our physical environment in response to the needs of a growing and diverse demographic. When the developer takes time to research a land parcel (or parcels) relative to the people it will serve, then the planning and creation of a new place yields a product worthy of respect for generations to follow. This initial goal to understand people, their history, and their sense of place lays the foundation for developing a research file important to land development efforts.

As explained in Chapter 4, many considerations are part of the identification of historic properties. The level of required regulatory review (i.e., federal, state, or local) ultimately guides both the identification of historic properties and any subsequent, formal impact assessments. As part of an impact assessment, a full understanding of the proposed project is required, as well as any alternatives developed during the project design. Although some land development projects may result in adverse impacts to historic resources (such as physical destruction or visual intrusions), it is important to note that land development projects can also produce positive impacts by remedying an existing condition that is detrimental to the historic property (poor drainage, erosion, limited access, etc.).

The goal of this chapter is to provide guidance for the assessment of potential impacts when a historic property might be affected by a proposed land development project. Further, the basic tenets of preservation are discussed in terms of site planning and design strategies that make use of unique historic architectural or archaeological resources as opportunities for project enhancement. Examples provided in this chapter demonstrate how preservation of historic properties should not be perceived as an obstacle to development, but as a beneficial means to preserve our nation's heritage while challenging the design professional to incorporate the consideration of historic properties into the schematic and final design phases of a proposed project.

IMPACT ASSESSMENT

Many land development projects that are subject to environmental review require an assessment of whether historic properties might be impacted by project activities. The level of assessment varies depending on the regulations being followed; the impact assessment may be an independent report or part of a larger study, such as an environmental impact statement (EIS) that looks at potential impacts to several environmental disciplines. Generally, as part of an impact assessment, an overview of the proposed project, including the project limits and study area boundaries, is provided. The next step in the assessment is to define existing conditions. This includes the identification of any historic resources (see Chapter 4) that are located within the study area. The impact assessment then looks at whether the proposed project would impact the identified historic resources located in the study area. If adverse impacts are anticipated, often consultation with the local community and local officials, as well as any involved state and/or federal agencies, is required to resolve adverse impacts and develop mitigation measures.

A well-documented impact assessment is a time-consuming, detailed, fact-gathering process, which serves to clarify cultural, material, architectural, landscape, and physical characteristics of a site, district, person, or location. This effort is well worthwhile when it comes to public hearings and community meetings on the land development project—preservation is an extremely personal issue for many citizens and government officials. Proper documentation exhibits a developer's commitment to the community, to the established protocol, and to a high-quality work product, whether the resource is preserved, reused, or removed.

Defining Impacts

When assessing potential impacts to historic resources, both direct and indirect impacts are considered. Direct physical impacts include demolition, alteration, or damage from construction on nearby sites. Indirect, contextual impacts include the isolation of a property from its surrounding environment or the introduction of visual, audible, or atmospheric elements that are out of character with a property or that alter its setting.

Many local municipalities have specific local laws or ordinances that define the level of assessment that would be required at the local level. Many states also have specific requirements that must be followed for state actions. As explained in greater detail in Chapter 2, many federal laws exist that require a review of potential impacts to historic properties, such as the National Environmental Policy Act, Section 106 of the National Historic Preservation Act of 1966, and Section 4(f) of the U.S. Department of Transportation Act of 1966.

The National Historic Preservation Act is the nation's primary historic preservation law. Section 106 of this law establishes procedures to be followed by federal agencies whose actions may have an effect on historic properties and directs those agencies to consult with the State Historic Preservation Officer (SHPO) to assess those effects. When assessing impacts under Section 106, the criteria of adverse effect (36 CFR Part 800.5[a]) is applied in order to determine whether an adverse effect will result from a proposed undertaking. In general, a proposed project is deemed to have an adverse effect if it would alter a historic property in a manner that would diminish any of the characteristics of the property that qualifies it for inclusion in the National Register of Historic Places. Adverse effects on historic properties include, but are not limited to:

- Physical destruction, alteration, or damage to all or part of the property
- Removal of the property from its historic location
- Change of the character of the property's use or of physical features within the property's setting that contribute to its historic significance
- Introduction of visual, atmospheric, or audible elements that diminish the integrity of the property's significant historic features
- Neglect of a property that causes its deterioration

Although not all land development projects would be subject to review pursuant to Section 106, this definition of an adverse effect can be useful when trying to determine whether a proposed project might result in adverse impacts to historic properties.

Avoidance, Minimization, and Mitigation

If historic properties are identified on or near a proposed project site, the primary goal of the design should be to avoid an adverse impact to the historic property. If avoidance is not feasible, then the next step is to minimize the impact to the historic property. Depending on the federal, state, or local regulation being followed, consultation with the local municipality and/or State Historic Preservation Office might also be required. If after careful consideration of all avoidance and minimization strategies it is found that a proposed project would adversely impact a historic resource, mitigation measures may need to be developed. Often, the finding of an adverse impact will not stop a project from moving forward, but will add additional consultation and review time—all these factors can also lead to additional project costs and increased time for the project schedule.

There are many types of mitigation strategies that may be employed to resolve adverse impacts to historic properties. At the federal and the state level, consultation usually results in a Memorandum of Agreement (MOA), which outlines agreed-upon measures to avoid, minimize, or mitigate adverse effects. Some common examples of mitigation include the following:

- Photographic documentation (i.e., photographs of historic properties or archaeological findings documenting their current condition before project activities begin)
- Historic research (e.g., researching the significance and background of properties within an appropriate historic context)
- Salvage and/or reuse of historic materials (e.g., salvaging historic materials from properties slated for demolition and reusing these materials on other historic buildings or other aspects of the project design)
- Context-sensitive design (i.e., developing an approach to planning and design based on active and early partnerships with communities)
- Adaptive reuse (i.e., adapting buildings for new uses while retaining their historic features)
- Public outreach (e.g., open communication with the public through announcements, public materials, public meetings, etc.)
- Public informational displays (e.g., display materials housed at local libraries, community centers, or other public space)

TREATMENT OF HISTORIC PROPERTIES

The secretary of the interior's *Standards for the Treatment of Historic Properties* (the *Standards*), defined at 36 CFR Part 68, provides guidance to property owners and preservation professionals on how to protect historic properties. Although adherence to the *Standards* may not be required to satisfy local or state regulations, they are important principles in the preservation field and can provide valuable guidance regarding the treatment of historic resources for any land development project. Following the *Standards* can help to avoid or minimize adverse impacts and can also be utilized to develop successful mitigation measures.

As summarized from the *Standards,* four treatment approaches are recommended: preservation, rehabilitation, restoration, and reconstruction. These approaches are defined in hierarchical order:

1. *Preservation:* The act or process of applying measures necessary to sustain the existing form, integrity, and materials of a historic property. Work, including preliminary measures to protect and stabilize the property, generally focuses on the ongoing maintenance and repair of historic materials and features rather than extensive replacement and new construction. New exterior additions are not within the scope of this treatment; however, the limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a preservation project.

2. *Rehabilitation:* The act or process of making possible a compatible use for a property through repair, alterations, and additions while preserving those portions or features that convey its historical, cultural, or architectural values.

3. *Restoration:* The act or process of accurately depicting the form, features, and character of a property as it appeared at a particular period of time by means of the removal of features from other periods in its history and reconstruction of missing features from the restoration period. The limited and sensitive upgrading of mechanical, electrical, and plumbing systems and other code-required work to make properties functional is appropriate within a restoration project.

4. *Reconstruction:* The act or process of depicting, by means of new construction, the form, features, and detailing of a nonsurviving site, landscape, building, structure, or object for the purpose of replicating its appearance at a specific period of time and in its historic location.

The secretary of the interior has also issued *Guidelines for Preserving, Rehabilitating, Restoring and Reconstructing Historic Buildings* (the *Guidelines*) that have been published with the *Standards.* While the treatment standards are designed to be applied to all types of historic properties (i.e., buildings, sites, structures, districts, and objects), the *Guidelines* apply specifically to buildings. These guidelines may also be consulted when working with a building in order to develop appropriate treatment approaches.

It is important to note that choosing the most appropriate treatment requires careful decision making about a property's relative importance in history, its physical condition, and the proposed use of the property, as well as mandated code requirements that would need to be followed as part of the proposed project.

PROFESSIONAL QUALIFICATION STANDARDS

Impact assessments for historic resources must be conducted by a qualified professional in order to ensure the accuracy and validity of the evaluation. Professional qualification standards have been developed by the National Park Service (36 CFR Part 61) in order to assist in the identification of qualified professionals in the disciplines of history, archaeology, architectural history, and historic architecture. These qualifications define minimum education requirements and experience levels that are required to conduct the identification, evaluation, registration, and treatment of historic properties. It is advised that these qualification standards be consulted when choosing an appropriate professional to prepare an impact assessment.

SUCCESSFUL PRESERVATION DESIGN EXAMPLES

McNair Farms

A case study involving documentation is offered to illustrate how a local jurisdiction handled the demolition and redevelopment of a former dairy farm property. In response to a developer's request for the rezoning of two tracts of 203 acres and 10 acres, respectively, Fairfax County, Virginia, required that the improvements associated with both parcels be documented in a manner consistent with the secretary of the interior's *Standards.* Early in the project's planning stages, the county determined that despite the properties' ineligibility for listing in the State and National Registers of Historic Places, the improvements were among the few remaining vestiges of the county's once abundant agricultural industry and therefore was of historic importance. The county stipulated that both land tracts, proposed for development as a planned residential community with supporting commercial entities under the former name of the principal land use (the McNair Dairy Farm, renamed McNair Farms), be documented for historic records.

At the time of original developer purchase, the McNair Dairy Farm (shown in Figure 16.1) was one of four remaining dairy farms in the county. By September 1988, when land planning for the project was well under way, there was only one remaining, 471-acre, dairy farm in Fairfax County. The rapid urbanization of Fairfax County can be clearly understood in context with agriculture. In 1969 there were 218 farms, including 200 dairy farms, with an average size of 130 to 146 acres, in Fairfax County. While a hard way of life, dairy farming was economically successful and the backbone of the county's agricultural heritage.

Fairfax County's urban growth can be measured in population changes, from 25,000 residents in 1930, to 40,929 in

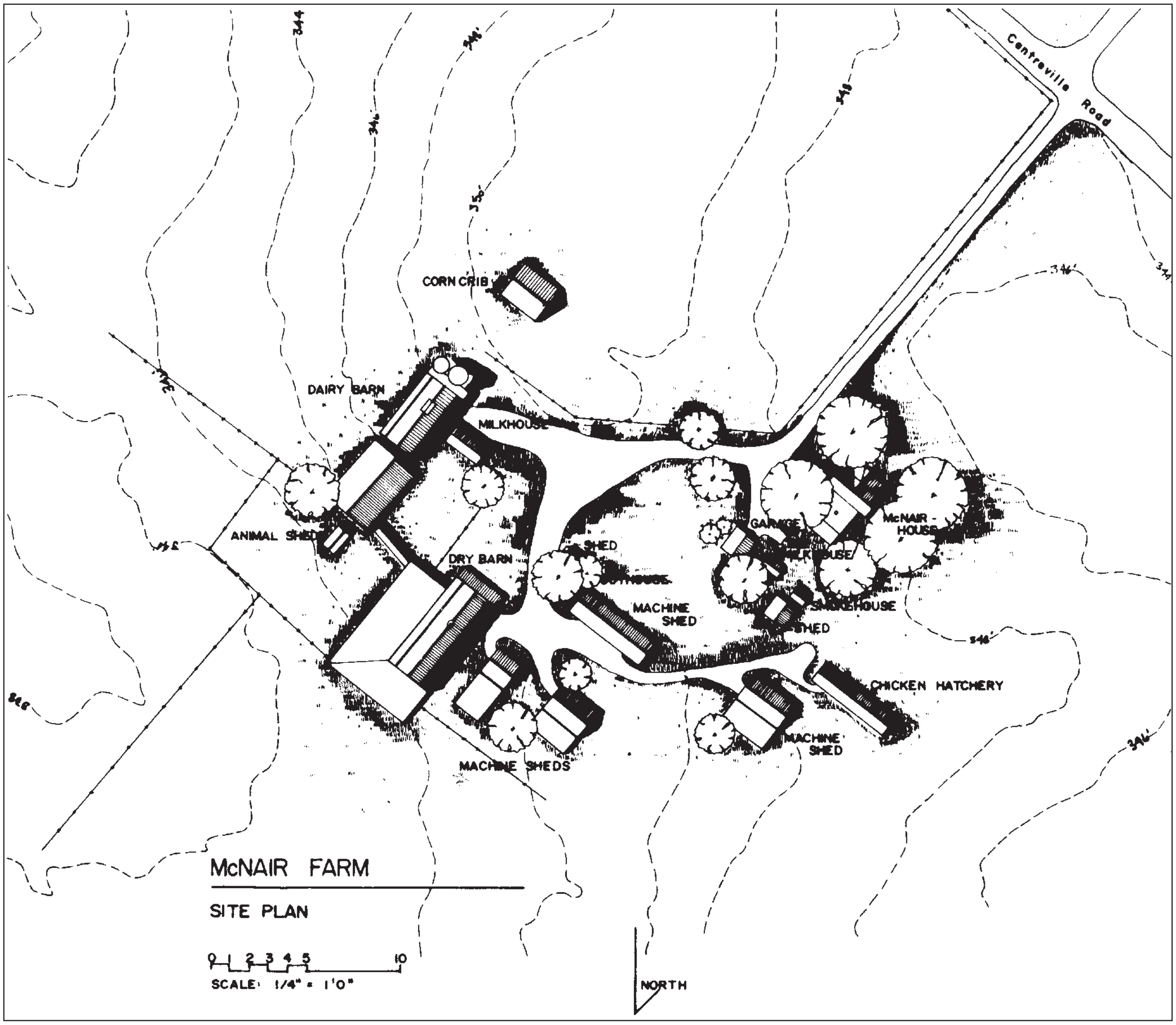

FIGURE 16.1 McNair Farms.

1960, to 455,021 in 1970, and ultimately to a current density exceeding 1 million. In less than 30 years the peaceful rural character of the county was transformed into a thriving urban extension of Washington, D.C. The pace of land activity and the real and perceived loss of the county's agricultural heritage prompted public requirements that the McNair Dairy Farm and the adjacent Hoffman property be documented.

A site survey was conducted to record the location and dimension of all improvements and landforms. This included 23 structures, extensive fence lines, two ponds, and several groves. Land records were searched and a historic profile drafted; former landowners and neighbors were interviewed. Site artifacts were identified and photographed. Measured drawings were prepared for seven buildings, and field note sketches were drawn for all improvements. Four site plans were generated based on the engineering survey. The U.S. Department of the Interior assisted in providing the Mylar sheets and technical assistance. Photographs, slides, field notes, and drawings were prepared with assistance from students and part-time employees.

The outcome of this documentation effort proved beneficial in several ways. Not only did the information fulfill requirements set forth by the county, but it augmented site design, farmhouse relocation and reuse planning, and business relations. The process brought people together, opened communication, and broadened the base of project information for future environmental and funding requirements. The cost of the study was less than 1 percent of the planning and design fees for the development project.

Chesapeake and Ohio (C&O) Canal

President John Quincy Adams enacted construction of the Chesapeake and Ohio (C&O) Canal on July 4, 1828, with the belief that it would expand economic trade and land development west from Washington D.C., the nation's capital, along the Potomac River to locations in western Virginia and West Virginia. Construction ended in 1850. Public and private investment exceeded 7.5 million. The canal was 184.5 miles long, up to 60 feet wide, and 6 feet deep, with one tunnel (3,118 feet long) and 74 locks. Each lock location spurred the economic growth of a small community. Severe floods in 1889 and 1924 closed the canal. Reconstruction failed after the 1924 flood.

Use of the canal diminished, and it quietly closed years later. Preservation efforts began in 1971; canal remnants were determined significant to our nation's history. Various sections of the canal in Maryland and Virginia were restored as public parks. Thirty years later archeological and building reconstruction efforts remain strong. (See Figure 16.2.)

In 1998, Dewberry and Davis architects, engineers, and resource staff started inspecting and documenting all structures, parts of and whole, along the 184.5-mile-long path. More than 2100 photographs and inspection-finding reports are now on file for public use.

It is important to note that, even today, any land development effort with views of and/or a location near the canal hold accelerating economic value; people value the historic context and aesthetic setting. Clearly President Adams's goal for expanded economic growth and development along the Potomac River has been realized.

Franklin Farm

Franklin Farm (see Figure 16.3) is a planned residential and commercial community in western Fairfax County, Virginia. This 828-acre project sought to perpetuate the agricultural farm imagery long associated with the property to distinguish it from the surrounding suburban housing developments. Site design and landscape elements incorporated a rural agricultural imagery with the retention of three farm buildings, ponds as part of stormwater management, and tree groves as visual buffers between residential homes.

Figure 16.2 Photo of C&O canal lock reconstruction.

Figure 16.3 Aerial view, Franklin Farm with silo and barn evident. (Photo courtesy of Larry Olsen)

Fencing and signage details were also designed to augment the imagery.

More strikingly, community building and retail elements were designed with finish materials to evoke an imagery associated with agricultural vernacular architecture. The development program for Franklin Farm included 1300 single-family residences, 330 townhomes, several community recreation centers, parks, and a shopping center, all of which was not dissimilar to other planned residential communities of comparable size located nearby.

Two former farm buildings, the dairy barn and the milkhouse, sited at the entrance of the large community, were rehabilitated for contemporary use as a day care center. The silo (shown in Figure 16.4) was converted to a private residence. Each required extensive study, design, and public review. Each offered distinct challenges in terms of design requirements and permit processing. Each stands today as a landmark image within the community of Franklin Farm and a tribute to the agricultural heritage of Fairfax County. The silo was converted into a five-level residence of 3100 square feet. It has received numerous awards for architectural design, preservation, and innovative use of building materials.

The rehabilitation of the dairy barn and milkhouse as a day care center was an equally challenging tribute to architectural adaptive reuse. Given the stringent safety and health requirements associated with its principal occupants—children—and the unique requirements for recreation, administrative, handicap, and educational facilities, the 6000-square-foot center provides a high-profile community resource distinguished by numerous awards.

Together, these two structures, the community name, and the site development theme are a continual reminder to the greater community that there is a unique history to the site. That history is perpetuated in a contemporary land development response. The 75-foot-tall silo is a visual landmark, symbolizing joint public and private efforts to retain images of and appreciation for the agricultural heritage of the county.

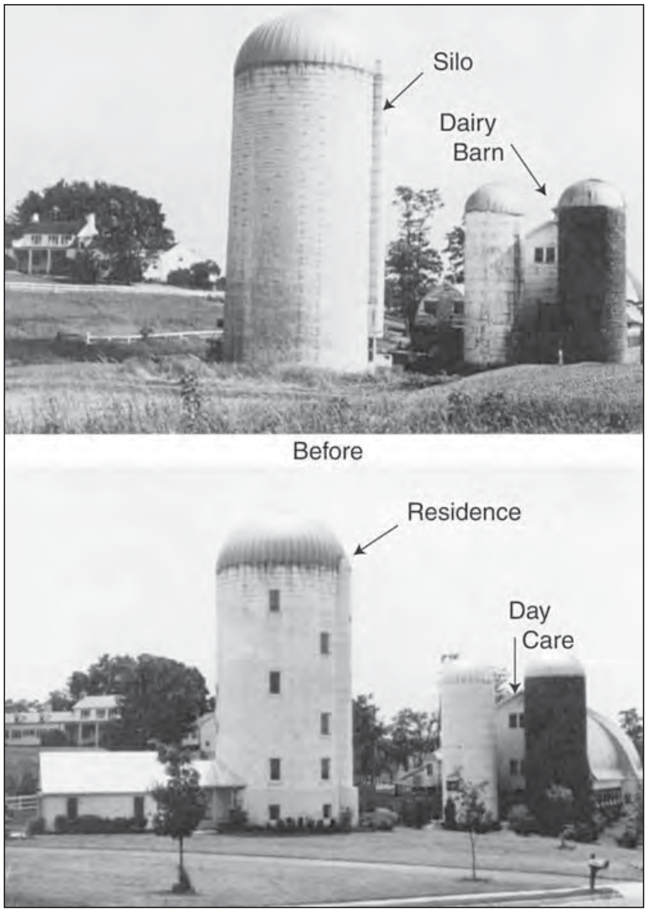

FIGURE 16.4 Before and after view of silo with dairy barn. (Photo courtesy of Joel Grimes)

Riverside Drive

Architecture and landscape architecture, as professions, have a long record in producing products of noted preservation value. Of current and increasing importance are the products of engineering. Rising attention is being paid to engineered accomplishments as a new, evolving repertoire of historic resources within the American landscape. The plethora of highways, tunnels, bridges, subways, and water dam construction, often affiliated with buildings and distinct landscaped settings, and most notably built more than 50 years ago, are often subject to major upgrading and reconstruction. The age and location of many engineered structures now raise the question of their historic architectural and archeological resource value. Riverside Drive is a representative example.

Riverside Drive, a primary transportation link that ultimately leads from Manhattan to the Merritt Parkway in Connecticut, was built with design influence from Frederick Law Olmsted as documented in six sets of plans (dated from 1875) on file at the National Olmsted Historic Archives in Brookline, Massachusetts. The importance of this drive, and the maintenance and reconstruction of the viaduct (see Figure 16.5), cannot be overemphasized, as the highway overall extends past New Haven, Connecticut, under various highway names and includes historic consideration of over 60 bridges.

Most of the bridges are between 30 and 75 years old, most connect places of historic significance, and many were either designed by or influenced by the works of Frederick Law Olmsted and his firm. Olmsted, by act of Congress, is declared to be the father of landscape architecture in this nation. Central Park in New York City is perhaps Olmsted's most renowned work, yet of quiet and equal historic importance are many of those streets and bridges he helped to develop between 1857 and 1883. These were his years of active practice while living in the city before moving his office to Brookline, Massachusetts.

By virtue of Olmsted's participation in the original design of the parkway, the structures and related settings have also occasioned archaeological interest, as many of the bridges traverse water bodies along which colonists settled during the sixteenth and seventeenth centuries. The importance of this example is twofold. First, the aging infrastructure of cities (particularly roads, bridges, and dams) points to a tremendous number of future historic resources, or at minimum to a deluge of historic evaluations and documentation with regard to the reconstruction of engineered structures important for modern living yet clearly representative of past technical accomplishments. The second point to note is that private development plays an ever-increasing role in communal infrastructure and services. Whether as part of a large, planned community or as part of a zoning proffer commitment, the number of structures privately built for general public use has grown steadily since Olmsted's first subdivision for private development, Riverside, near Chicago, in 1858, and the enactment of zoning during the twentieth century. Land developers, contractors, engineers, and designers should be aware of this growing preservation repository and its implications for all future private land development efforts.

FIGURE 16.5 Riverside Drive viaduct (124th Street southwest, circa 1927).

SUMMARY

As these case studies demonstrate, the consideration of historic properties can contribute to successful design development and project marketing. In each case, the identification of unique land features, artifacts, and historic architectural and archeological resources helped shape the land development project design response. Historic resources became a component of the larger development program or, by virtue of association, became incorporated into a unique marketing tool, such as name recognition.

As development interests understand their increasing role as a part of preservation, the preparation and the formulation of strong advocacy plans toward the realization of land changes will take place with greater ease. Such increased awareness will open opportunities for reasonable public and community participation, with fewer gridlocks. New insight will also be gained in terms of options for appropriate treatment of a particular historic resource if identified on or near a property and incorporated into the land design process.

The process of identifying and assessing impacts to historic resources should challenge development and design professionals to a higher level of design, marketing, and financial solutions. While issues regarding the fair and reasonable costs associated with preservation activity, as well as the perception of abridged rights and control over private property, continue to be in contention, ask yourself this: What are the consequences—fiscal, environmental, and in terms of scheduling—of neglecting history?

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CHAPTER 17

BROWNFIELD REDEVELOPMENT AND ENVIRONMENTAL CONSIDERATIONS

David Bausmith, PE

INTRODUCTION

So *what is* a brownfield? The reality is that what defines a brownfield depends on a variety of factors and, in a crude sense, the only thing that differentiates a brownfield property from any other property is that brownfields have a persistent track record of not being *used* as a result of environmental concerns. The U.S. Environmental Protection Agency (EPA) defines *brownfields* as "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant." Many states, such as New Jersey,[1] have adopted similar definitions of a brownfield, yet all are unified on the notion that future use of the property is compromised by the perceived or real presence of contamination. (See Figure 17.1.) A brownfield could range from a several-hundred-acre chemical plant with clear evidence of discharged contaminants to a half-acre vacant property containing illegally dumped refuse but no actual contamination.

This chapter focuses on the challenges and opportunities of one of the fastest-growing land development markets in the United States: brownfield redevelopment. This market, ironically, is largely a result of the industrial revolution that occurred during the twentieth century and established the United States as one of the most prosperous societies in the world. Unfortunately, the decline of the industrial revolution and other socioeconomic changes left behind a surplus of abandoned or underutilized industrial and commercial properties across the country that have a variety of real or perceived environmental concerns. Traditionally, these properties remained untouched and their environmental issues unresolved, because of the potential liability associated with their purchase or development. This concern resulted in relatively unimpacted property remaining idle because developers, who otherwise would redevelop brownfield properties, pursued virgin land, or *greenfields,* to avoid the potential liability associated with brownfields.

In an effort to protect human health and the environment while also conserving greenfield sites, federal and state regulators have clarified environmental cleanup liability and are fostering the remediation and appropriate reuse of brownfields through regulatory and financial incentives. Although once the bane of commercial developers, increasing demand for well-located property coupled with a variety of regulatory constraints on greenfields and smart growth initiatives are compelling developers to reconsider brownfield properties. Additionally, redevelopment of brownfields is increasingly favored by the U.S. Green Building Council and related third-party sustainable design organizations that afford rating points or credits to such projects—reference LEED-NC Sustainable Sites Credit 3 Brownfield Redevelopment.

BROWNFIELDS BY THE NUMBERS

Brownfields come in a variety of forms, including large former industrial and commercial properties, vacant buildings, landfills, agricultural facilities, or small abandoned gas stations. By definition, these properties often include dilapidated buildings, equipment, storage tanks, or other visible signs of potential contamination; however, seemingly innocuous parcels located in rural areas may also fit the definition of a brownfield based on their historic use. In

[1] A brownfield is defined under New Jersey state law (N.J.S.A. 58:10B-23.d) as "any former or current commercial or industrial site that is currently vacant or underutilized and on which there has been, or there is suspected to have been, a discharge of a contaminant."

FIGURE 17.1 Former industrial site (*a*) before development, and (*b*) after development. (Photo courtesy Alan Schindler ©2006)

urban areas, brownfields are often located in urban/city centers and proximal to waterfronts and historic rail/vehicular transportation service areas because of the critical service that these features provide for industrial operations.

Brownfields, particularly those in city centers, contribute to blight and joblessness in surrounding communities. The City of Long Beach, California, once the proud home of a thriving military and aerospace industry that generated thousands of jobs, is one such example. The city was devastated in the 1990s by the closure of various military facilities and struggling aerospace companies such as McDonnell Douglas, which was forced to lay off thousands of workers.

In total, the community of Long Beach lost over 58,000 jobs, with economic losses totaling $4 billion (U.S. Conference of Mayors, 2006).

Unknown environmental liabilities prevent communities, developers, and investors from restoring these properties to productive use and revitalizing impacted neighborhoods, even though the majority of brownfields are not severely contaminated. According to the EPA, only about 8 percent of all brownfields are contaminated to a degree sufficient for consideration on the National Priorities List (NPL)—a list of the nation's worst hazardous waste sites—with less than 1 percent actually placed on the NPL. Therefore, at least 99 percent of all potential brownfield properties nationwide do not require the most serious EPA designation or corresponding cleanup action.

Market Growth

The growth of the brownfield redevelopment market is related to a combination of regulatory and financial incentives, scarcity of affordable properties, public perception changes, and socioeconomic changes. The EPA's Brownfields Program was created in 1995 and has changed the way contaminated property is perceived, addressed, and managed. The EPA's Brownfields Program is designed to empower states, communities, and other stakeholders in economic redevelopment to work together in a timely manner to prevent, assess, safely clean up, and sustainably reuse brownfields. Cleaning up and reinvesting in these properties increases local tax bases, facilitates job growth, utilizes existing infrastructure, takes development pressures off undeveloped, open land, and both improves and protects the environment.

Accurate statistics regarding the number and distribution of brownfields are difficult to obtain due, in part, to the subjective definition of a brownfield. It may take years for local, state, and federal officials to obtain an accurate inventory of properties for which expansion, redevelopment, or reuse might be complicated by real or perceived contamination. In 1995, the EPA estimated that 450,000 brownfields existed nationwide, although a more recent study indicated that up to 1 million exist in the United States. A recent report (GAO, 2004) presented in 2006 by the U.S. Conference of Mayors indicated that, of the 200 cities surveyed, approximately 80 percent estimated that they had more than 23,810 brownfield sites averaging between approximately 5 and 15 acres in size and totaling approximately 96,000 acres of land.

The accuracy of brownfields inventories also depends on the industrial maturity and regulatory environment of reporting districts. Officials in urban areas that experienced the extreme increase and subsequent decline of industrial prosperity between the early and late twentieth century, recognized the importance of redeveloping vacant industrial areas and may, therefore, conservatively overestimate the number of brownfields. In urban areas that experienced industrial growth primarily during the second half of the twentieth century, the number of brownfields is expectedly underestimated. Such was the case with Atlanta, Georgia, where the official-reported brownfield acreage in the year 2000 was approximately 85 percent lower than the actual known and potential brownfield acreage (Leigh and Coffin, 2005). Additionally, many officials remain reluctant to report the existence of brownfields in their jurisdictions because of the perceived stigma. Despite these difficulties, the number of identified brownfields nationwide continues to grow and an increasing number of financial and regulatory incentives are helping fuel developer interest in brownfields.

Regulatory Incentives

The 2002 federal Small Business Liability Relief and Brownfields Revitalization Act (SBLR-BRA), commonly referred to as the Brownfields Law, has fueled investor interest by giving buyers of the sites additional liability protection, cutting one of their biggest risks. Through passage of the SBLR-BRA, effective policies that the EPA developed over the years were passed into law. The Brownfields Law expanded the EPA's assistance by providing new tools for the public and private sectors to promote sustainable brownfields cleanup and reuse. EPA's brownfields assistance has leveraged more than $9.6 billion in cleanup and redevelopment, helped create more than 43,000 jobs, and resulted in the assessment of more than 10,500 properties and the cleanup of approximately 200 properties.

Historically, under the Comprehensive Environmental Restoration, Compensation and Liability Act (CERCLA) or Superfund, there were environmental liability risks for developers associated with acquiring title to contaminated property even if no disposal of hazardous substances had taken place during their ownership. The SBLR-BRA now provides liability defense for the "innocent landowner" who did not know or had no reason to know of a prior release of hazardous substances on the property. Developers should note the importance of conducting an All Appropriate Inquiry in addressing this requirement as part of their preacquisition due diligence (see "Site Characterization and Investigation"). Additionally, the SBLR-BRA created a defense for a purchaser who acquires property *with* knowledge of the contamination, provided certain conditions are met. This is the "bona fide prospective purchaser." The bona fide prospective purchaser provisions represent a significant change in CERCLA because, for the first time, a party may purchase property with knowledge of contamination and not acquire liability under CERCLA as long as that party meets certain criteria. States have followed with similar legislation aimed at limiting a prospective developer's potential liability. New Jersey's Brownfield and Contaminated Site Remediation Act (BCSRA), for example, advances brownfields reuse by providing liability protection including no-further-action letters, with a covenant not to sue, to nonliable developers who remediate property under the oversight of the New Jersey Department of Environmental Protection.

On December 20, 2006, President Bush signed the Tax Relief and Health Care Act of 2006 that included an extension and expansion of the Brownfields Tax Incentive. The incentive was renewed, effective after December 31, 2005, and extended until December 31, 2007. The Brownfields Tax Incentive allows environmental cleanup costs to be deducted in the year incurred, rather than capitalized over time. The legislation expanded the Brownfields Incentive's scope, allowing the deduction of expenses for the cleanup of petroleum products (crude oil, crude oil condensates, and natural gasoline), which had previously been ineligible. The U.S. Department of the Treasury (2007) reports that between 2008 and 2017, a total of $2.85 billion in tax incentives will be allocated for permanently expensing brownfields remediation costs incurred prior to January 1, 2008. This is one example of the U.S. government's commitment to encouraging remediation and redevelopment of brownfields.

Financial Incentives

Many think brownfield redevelopment is prohibitively expensive; however, there are a host of financial incentives available to brownfield owners and redevelopers, at the federal, state, county, and city levels to offset the additional costs often incurred during both the assessment and remediation phases of property development. The following are just some of the financial incentives available from federal, state, and local governmental sources. (Refer to Table 17.1.)

Grants

EPA Brownfield Pilot Program. The EPA provides Brownfield Pilot Grants to local, state, and tribal governments. Brownfield Pilot Grants, up to $200,000 for two years each, can be used for:

- Site investigation costs including site assessments
- Site identification
- Site characterization
- Site remediation plan development

The grants can also be used to facilitate coordinated public and private partnerships and conduct outreach activities. However, the money cannot be used for actual cleanup activities.

The brownfield pilot grants fund cleanup and redevelopment planning models, direct special efforts toward removing regulatory barriers without sacrificing protectiveness, and facilitate coordinated environmental cleanup and redevelopment efforts at all levels of government.

EPA Brownfield Job Training and Development Demonstration Pilot. The EPA provides funds for community groups, job training organizations, educators, labor groups, investors, lenders, developers, and other affected parties to provide:

- Job training for residents in affected communities
- Employment for the residents in the cleanup of brownfields
- Training for employment in the environmental field

These pilots provide up to $200,000 over two years. Eligible applicants include colleges, universities, nonprofit training centers and other 501(c)(3) entities, community job training organizations, states, cities, towns, counties, U.S. territories, and federally recognized Indian tribes.

EPA Local Governments Reimbursement Program (LGR). This program provides reimbursement of up to $25,000 to general-purpose local governments and Indian tribes where these entities do not have, or have exhausted, their own remediation funds. An application with receipts must be submitted within a year of the completion of the response, and reimbursement can take as little as two to three months. Incidents involving petroleum are generally not reimbursable, but may be considered where there is a mix of hazardous substances as defined in CERCLA. Reimbursement is made to the municipality with legal jurisdiction, and only one reimbursement is available per release. Responsible parties, including the municipality if applicable, are not eligible for reimbursement.

State Brownfield Redevelopment Grants. Many states have made tremendous strides in developing and implementing brownfield programs. Often, in addition to regulatory guidelines, loan and grant funds are set up through the state environmental protection authority or other responsible government agency. These funds can be accessed by government entities and private developers to facilitate brownfield redevelopment. For example, the Illinois Environmental Protection Agency administers the Municipal Brownfield Redevelopment Grant Program (BRGP; www.epa.state.il.us) for the purpose of providing financial assistance to Illinois municipalities for brownfield redevelopment–related activities, including:

- Brownfield site identification, investigation, characterization, and inventory
- Development of remediation objectives
- Development of remedial action plans

The grant amount can be up to $240,000, and grants are awarded to cover eligible or approved costs incurred by the municipality. The grant amount covers up to 70 percent of the specific project amount, with the municipality paying for the remaining 30 percent. Other states have similar programs.

HUD Community Development Block Grant. While not specifically earmarked for brownfield redevelopment, the Department of Housing and Urban Development (HUD) administers a Community Development Block Grant (CDBG; www.hud.gov) program that provides annual grants to be used for a wide range of community development activities. These activities include those directed toward:

- Neighborhood revitalization
- Neighborhood development
- Improved community facilities and services

TABLE 17.1 Partial List of Brownfield Incentives

	Recipients			Assistance			
Program	**Nonprofit**	**Government**	**Private**	**Loan**	**Grant**	**Tax**	**Other**
Federal							
Department of Housing and Urban Development							
Brownfields Economic Development Initiative (BEDI) Grants		X			X		
Section 108 Loan Program		X		X			
Environmental Protection Agency							
Brownfields Cleanup Revolving Loan Fund		X			X		
Internal Revenue Service							
Environmental Cleanup Cost Deduction			X			X	
Pennsylvania							
Department of Community and Economic Development							
Enterprise Zone Tax Credit			X			X	
Industrial Sites Reuse Program		X	X	X	X		
Infrastructure Development Program		X	X	X	X		
Job Creation Tax Credit			X			X	
Keystone Opportunity Zones			X			X	
Machinery and Equipment Loan Fund			X	X			
Opportunity Grant Program		X	X		X		
Pennsylvania Capital Access Program			X	X			
Pennsylvania Economic Development Financing Authority Bonds			X	X			
Pennsylvania Industrial Development Authority		X	X	X			
Pollution Prevention Assistance Account			X	X			
Small Business First			X	X			
Underground Storage Tank Upgrade Loan Program			X	X			
Department of Environmental Protection							
Underground Storage Tank Pump and Plug Program			X		X		
New Jersey							
Commerce and Economic Growth Commission							
Brownfield Site Reimbursement Fund	X	X	X			X	
Business Relocation Assistance Grant (BRAG) Program	X		X		X		
Municipal Landfill Closure and Remediation Fund	X		X		X	X	
Sustainable Development Loan Program	X		X	X	X		X
Urban Enterprise Zone Assistance Program	X		X			X	X
Department of Community Affairs							
Downtown Living Program	X		X	X			
Department of Environmental Protection							
Environmental Infrastructure Financing Program		X	X	X			
Environmental Opportunity Zone	X		X			X	

TABLE 17.1 (*Continued*)

	RECIPIENTS			ASSISTANCE			
PROGRAM	**NONPROFIT**	**GOVERNMENT**	**PRIVATE**	**LOAN**	**GRANT**	**TAX**	**OTHER**
HDSRF Innocent Party Grant	X		X	X	X		
HDSRF Limited Restricted Use/Unrestricted Use/ Innovative Technology Grants	X		X	X	X		
HDSRF Municipal Grants and Loans		X		X	X		
HDSRF Private Party Loans			X	X			
Sanitary Landfill Facility Closure and Contingency Fund	X	X	X		X		
Spill Compensation Fund	X	X	X		X		
Underground Storage Tank Remediation, Upgrade and Closure Fund		X	X	X	X		
Economic Development Authority							
Bond Financing	X	X	X	X			
Business Employment Incentive Program	X		X		X		
Direct Loan Program			X	X			
Fund for Community Economic Development			X	X			
Loan Guarantees	X		X	X			
Local Development Financing Fund	X		X	X	X		
Statewide Loan Pool for Business			X	X			
Urban Centers Small Loan Program			X	X			
Housing and Mortgage Finance Agency							
Assisted Living Construction and Permanent Financing	X	X	X	X			
Camden Housing Initiative	X	X	X	X			
Home-Buyer Mortgage Program			X	X			
Home-Plus Mortgage Program			X	X			
Low Income Housing Tax Credit Program			X			X	
Mortgage Opportunity Program			X	X			
Multi-Family Rental Housing Program	X	X	X	X			
One Hundred Percent Mortgage Program			X	X			
Purchase/Rehabilitation Mortgage Program			X	X			
Rental Housing Incentive Guarantee Program	X		X	X			
Too Good But It's True Mortgage Program			X	X			
Upstairs-Downstairs Program			X	X			
Urban Home Ownership Recovery Program	X		X	X			
Local Redevelopment and Housing Law	X	X	X				X
Redevelopment Authority							
New Jersey Redevelopment Investment Fund	X	X	X	X	X		
Urban Site Acquisition Program	X	X	X	X			

CDBG money has been used in the past for brownfield redevelopment projects. Larger communities—called Entitlement Communities—receive CDBGs directly from HUD. Small communities, however, can compete for CDBG money through the Community Development Assistance Programs administered by state governments.

Loans

HUD Section 108 Loan Guarantee Program. Eligible communities can gain financing for a variety of economic development projects through Section 108 loan guarantees, coupled with Economic Development Initiative (EDI) grants. Communities are able to take or provide loans secured by current and future CDBG funds. Some activities that Section 108 money can be used for are:

- Clearance and site improvement
- Economic development activities eligible under CDBG
- Acquisition of real property

Brownfield Cleanup Revolving Loan Fund (BRCLF). This EPA program provides up to $1 million over five years to states, political subdivisions, and Indian tribes for them to make low-interest loans for the environmental cleanup of brownfields (www.epa.gov). Eligible parties may include owners or operators of the contaminated site who had no part in contributing to the contamination but bought the land for purposes of restoring it. Certain properties are ineligible, including those on the NPL, or where removal action must be taken within six months, or where a federal or state agency is planning or conducting enforcement action.

Brownfields Redevelopment Loan Program. The Brownfields Redevelopment Loan Program is a revolving low-interest loan program that provides funds beyond the public sector to municipalities and the private sector for the environmental cleanup of brownfields sites. The loans will pay for limited investigation, remediation, and demolition costs at brownfields sites. The maximum loan amount for any single loan application is $500,000.

Other, more state-specific loan programs also exist to assist in brownfields redevelopment. For example, the Illinois Micro Loan Program provides loans up to $20,000 to existing small businesses located in Chicago for projects that create jobs. The program addresses the needs of very small businesses that cannot obtain conventional loans through banks. Loans are made at a flat 3 percent or at 75 percent of the prime rate, depending on location and type of business. Funds can be used for machinery, equipment, renovation, or working capital.

Brownfield Economic Development Initiative (BEDI). This is an umbrella program by which HUD and 15 other federal agencies coordinate brownfield remediation efforts and solutions. The HUD CDBG and Section 108 Loan Guarantee Program are among the resources available for a variety of activities by different entities to investigate and remediate brownfields in their communities.

Tax Benefits and Incentives

Federal Brownfield Tax Incentives. The Federal Brownfield Tax Incentive allows remediation costs incurred after August 4, 1997, and before December 31, 2003, to be fully deductible from gross income for the purposes of calculating federal income tax during the year in which the remediation costs are incurred.

To be eligible, hazardous substances must be present or potentially present on a property used in a trade or business, for the production of income, or included in the taxpayer's inventory. Any taxpayer who was involved in causing the property contamination is not eligible unless the property use is changing.

State Tax Credits. In addition to loans and grants, many states have passed tax incentives that may be utilized to facilitate brownfield redevelopment projects. For example, the Illinois Environmental Remediation Tax Credit (www.epa.state.il.us) is a financial incentive for the cleanup of brownfield sites by private parties under the Illinois Site Remediation Program. Businesses can take this credit against their Illinois income tax, equal to 25 percent of the eligible remediation costs in excess of $100,000 per brownfield site, with a maximum credit of $40,000 per year and a maximum total credit of $150,000 per site over time.

Tax Increment Financing. A Tax Increment Financing (TIF) program is a municipal financing technique that can be used to renovate declining areas or redevelop blighted areas while increasing the tax base of such areas. A TIF program allows a community to apply the increase in various local taxes that result from redevelopment to fund public improvements and business incentives. TIF proceeds can be used for a variety of redevelopment costs, including planning, legal and other services, employee training costs, property assembly costs, demolition of buildings, clearing and grading of land, building rehabilitation, and public investment in water and sewer line replacement. TIF districts have been established in most states.

ENVIRONMENTAL CONSIDERATIONS

The material presented in this section addresses some of the various types and sources of chemical contamination that might be encountered on a brownfield property, the environmental requirements for the management, and corrective action relating to the contamination and relevant environmental considerations for redevelopment of damaged or degraded sites including such issues as demolishing buildings, storage tanks, vapor intrusion, and historic fill.

Chemical contamination impacts air, water (ground water and surface water), and soils and is regulated through a variety of environmental regulations. Chemical contamination sources can be:

- Properties or facilities used for the direct disposal of materials
- Sites of indirect disposal of materials
- Nonpoint sources

Hazardous waste is likely to be the most serious chemical contamination on a site and is typically related to industrial activities. *Hazardous waste* refers to discarded waste materials from institutions, commercial establishments, and residences that pose an unacceptable risk to human health and safety, property values, and the environment.

Before purchasing property for development, an environmental investigation and assessment should be performed, as described in Chapter 3. As part of these environmental assessments, a search into the history of the property is performed as well as an actual physical site survey and field reconnaissance. If the assessment identifies potential environmental concerns, environmental sampling (soil, ground water, air, etc.) is usually performed. If the environmental sampling identifies a contamination problem, the contamination may need to be appropriately defined and remediated prior to development. In some cases, these detailed studies can take several months to complete and cost as much or more than the property was initially valued at. While the contributing sources of environmental contamination are highly variable, the processes for addressing contamination are fairly standardized. There are numerous written protocols for performing environmental assessments and investigations, discussed in further detail later in this chapter. The protocols include checklists that document areas and items to consider. The list of potential contributing sources of chemical contamination of property is too lengthy to discuss in this chapter; however, several of the more common sources of contamination found today are presented in the following paragraphs.

Contamination Sources

Hazardous Building Materials. Often, the development of land requires the demolition of the existing structures. Similar to environmental site audits, surveys of the existing structures should be performed to determine whether hazardous materials are present. Although there are several reasons to perform these surveys, the predominant reason is that regulations in most states require the safe handling and disposal of hazardous materials. This is particularly true of asbestos, lead-based paint, and ozone-depleting substances—most states and/or the federal government have regulatory requirements that affect the disposal of such materials. Other reasons for knowing the location(s) of hazardous materials within the existing structures include:

- Protecting the developer's/contractor's workers
- Reducing potential financial liability to the developer ("not knowing" is not an excuse)
- Minimizing the amount of hazardous waste generated (and disposal costs)
- Ensuring that hazardous materials are not spread throughout the site
- Protecting the public and environment at large
- Eliminating public outcry and bad press by doing the right thing

Based on the previous use of a property and its structures, there can be many types of hazardous materials in a structure. A qualified environmental firm should be hired and consulted not only to identify these materials, but also to recommend a method for the proper demolition and disposal of these materials. The treatment and disposal of hazardous materials in structures varies by region and state, so it is recommended that the environmental firm be knowledgeable with respect to all regulations, but particularly to state and local regulations. Pertinent federal regulations applying to hazardous material demolition will be cited in this chapter.

Although asbestos and lead-based paint (LBP) tend to cause the most significant cost implications when demolishing existing structures, universal wastes should also be properly identified and managed. Universal wastes are hazardous wastes that contain mercury, lead, cadmium, copper, and other substances hazardous to human and environmental health. In general, universal waste may not be discarded in solid-waste landfills. Examples of these wastes are batteries, fluorescent tubes, and some electronic devices.

Since the presence of asbestos-containing materials (ACM), and in some cases LBP, in structures to be demolished (or renovated) can place a greater worker, public, environmental, and financial liability on the developer, these materials are discussed in greater detail.

Asbestos. Asbestos concerns in land development consist primarily of the control of airborne fiber releases during the demolition of existing structures that possess ACMs, excavation and disturbance of naturally occurring asbestos, and the removal of asbestos-containing debris from dumps or piles located on the property. In each case, provisions for the control of airborne asbestos fiber releases, exposure to workers, and the proper containerization, transportation, and disposal of ACMs are required.

Asbestos is a broad term for a group of naturally occurring hydrated silicates that crystallize in a fibrous habit. Asbestos fibers in ores cannot be inhaled until released and made airborne during excavation, mining, and processing. Asbestos is a known human carcinogen (cancer-causing substance). Exposure to asbestos fibers can cause several different types of asbestos-related diseases. The primary exposure route of concern is inhalation; however, asbestos fibers can be ingested. Asbestos is not normally absorbed through the skin. Exposure to large concentrations of asbestos can result in the disease asbestosis. Asbestosis, a chronic scarring disorder of the lower respiratory tract, occurs when asbestos fibers lodge in the lungs. A unique form of cancer, which is directly related to asbestos exposure, is mesothelioma. Mesothelioma tumors are the uncontrolled growth of cancerous cells in the lining of the chest cavity (pleura), between the chest walls and lungs, or in the lining of the abdominal cavity (peritoneum). It is important to note that many cases of mesothelioma are associated with relatively low levels of asbestos exposure as well as exposures of even short duration. Additionally, the latency period for mesothelioma is long; some cases have been reported with as many as 40 years passing between exposure and the onset of the disease. Mesothelioma is an incurable form of cancer and is usually fatal within one to two years from diagnosis.

The EPA requires the control of airborne visible emissions of asbestos under the National Emission Standards for Hazardous Air Pollutants (NESHAPs) regulations (40 CFR 61, Subpart M). For the most part, it will be the NESHAPs regulations that a developer demolishing structures will be required to follow. Many local jurisdictions ensure that asbestos concerns are addressed during building demolition (or renovation) by requiring an asbestos survey as part of the demolition permit process. It is important to note that under NESHAPs, certain building material forms of ACMs within a structure do not need to be removed before demolition. Rather, under certain conditions, they can be included in the waste stream with the other building demolition materials and disposed of in an approved construction debris landfill. It is highly recommended that a developer contact a local knowledgeable environmental firm to assist in this process, as they should know local regulations and understand what the requirements are for this process. The EPA also requires the proper disposal of asbestos-containing or contaminated materials, and the proper containerization, transportation, and disposal of ACMs at approved landfills. In addition, EPA, through its regulation 40 CFR 763, among other items, requires training for asbestos inspectors and workers, which most states regulate through a licensing program.

Identification of asbestos or ACMs consists of the sampling and laboratory analysis of suspect materials. The primary methods of asbestos identification involve microscopic inspection of bulk samples or pieces of suspect materials. Polarized light microscopy (PLM) is probably the most common type of laboratory identification of asbestos and the least costly type of analysis.

Phase contrast microscopy (PCM) is used in determining asbestos exposure concentrations to workers occupationally exposed to asbestos. The analysis of air samples for asbestos involves collecting the fibers on filters connected to air sampling or suction pumps that are set at a given flow rate to collect an adequate volume of air for analysis.

The more sophisticated types of microscopic analysis such as transmission electron microscopy (TEM) and scanning electron microscopy (SEM) are used to detect asbestos that is present in a very tight matrix or very bound ACM. TEM is also used in the analysis of air samples collected to determine airborne asbestos fiber concentrations. Note that TEM and SEM analysis costs are several times that of PLM and PCM and generally are not required for demolition projects.

Before development or property acquisition, or even the digging or excavation of a piece of property, investigation into the area geology should be performed as part of the environmental assessment and survey. The county soils science office should be contacted and the county soil survey reviewed to determine whether soil or geology within the area has characteristics of naturally occurring asbestos. Again, a local environmental firm knowledgeable in local conditions and able to assist a developer in determining the presence of naturally occurring asbestos and the process of working with it should be consulted prior to construction activities commencing.

Lead-Based Paint. Lead-based paint (LBP) concerns in land development consist primarily of the determination of whether LBP in a structure's demolition debris (waste stream) will cause that waste stream to be classified as a hazardous waste. Soil should also be tested around structures to determine whether it is contaminated by LBP from the structure. It is more cost effective to determine whether lead-contaminated soil is a result of LBP from a structure, as opposed to other sources of contamination.

A highly toxic heavy metal, lead was a major component of household paint until it was banned from residential use in 1978. As LBP ages, lead dust, chips, or flakes may enter the environment and can be ingested or inhaled. Medical research has determined that lead exposure—even at extremely low levels—can decrease intelligence, inhibit school performance, and impair memory attention and language function. Young children, pregnant women, and women in the childbearing years are particularly at risk from toxic lead. As a result, LBP and dust are recognized as a potential health hazard in buildings and other structures. Figure 17.2 shows peeling lead-based paint on a structure.

Because of these concerns, Congress passed the 1992 Residential Lead-Based Paint Hazard Reduction Act (42 U.S.C. 4851 et seq., PL 101-550). This act is commonly known as Title X by the industry. Title X established the framework for informing the public; the training and certification of inspectors, contractors, and laboratories; and protection of abatement workers. Therefore, states have and will be reacting to Title X and other concerns for protecting our nation's children from lead-based paint and dust by enacting legislation. The developer is probably most affected by the legislation promulgated by Title X with respect to protection of workers during the demolition of structures and the proper disposal of demolition debris. The Department of Housing and Urban Development (HUD) webpage (www.hud.gov/offices/lead/) regarding LBP is probably the best to access, review, and link to other websites, such as those for the EPA and the

FIGURE 17.2 Lead-based paint peeling from a structure.

Occupational Safety and Health Administration (OSHA), for LBP facts, programs, and regulations.

The objective, as with the other hazardous materials cited here, is to predict, prior to demolition, the disposal criteria for a waste stream from the demolition of a structure and to do everything legally possible to dispose of the waste stream in a properly permitted construction and demolition landfill, as opposed to a hazardous waste landfill. The test to determine whether LBP in a structure will cause the demolition debris (waste stream) of that structure to be considered hazardous is called the *Toxicity Characteristic Leaching Procedure* (TCLP). This is further discussed in 40 CFR 261.24.

Basically, performing a TCLP test to determine the disposal criteria involves the estimation and quantification (by percentage) of all building materials (regardless of whether they are painted) and the collection of these building materials in their representative quantities for submission to a laboratory for analysis. The laboratory takes these various materials and composites them (in their specified representative quantities) in a 100-gram sample to perform the TCLP test. If the result equals or exceeds 5 mg/L, the waste stream is considered characteristically hazardous; if under 5 mg/L, the wastestream is nonhazardous waste and can be disposed of in a construction and demolition landfill, in accordance with state and local regulations.

If the TCLP test equals or exceeds 5 mg/L, it is probably more economical for the developer to perform specific LBP testing to determine which components contain the LBP, and to abate (remove) those components prior to demolition. If a waste stream is predicted as hazardous waste due to LBP, then abatement of the LBP is generally recommended prior to the demolition of the structure to reduce the amount of hazardous waste. It is highly recommended that developers consult and hire an environmental firm that understands this issue; is familiar with federal, state, and local requirements; and can perform any required sampling and analysis.

Regardless of impending regulation for disposal, OSHA requires the protection of workers during the demolition of structures containing lead in paint. These requirements can be reviewed in 29 CFR 1926.62, Lead in Construction. An environmental firm can assist a developer in meeting these requirements.

The developer should also consider testing soil around structures for lead, resulting from the leaching or deterioration of LBP from the structure. This is a simple test for which soil samples are taken from the drip lines around a structure and bare soil areas in yards. These samples are taken from the top 0.5 inch of soil, typically composted, and sent to a laboratory for *total lead* analysis. A lead hazard is present if sample results equal or exceed 1200 parts per million. Lead contamination in soil resulting from LBP can be treated under the LBP regulations found in TSCA as opposed to the requirements under CERCLA, which tend to be more costly and may take more time to abate and monitor. Again, an environmental firm should be hired to consult the developer about this process, as different states and local jurisdictions may view this process differently. The environmental firm should also be knowledgeable in collecting, processing, and analyzing the soil samples.

If a developer intends to reuse a structure (i.e., renovate), surface-by-surface inspection should be performed to determine exact locations of LBP. This is necessary to protect workers performing the work during renovation, as well as to inform the future occupants of the structure (if the LBP was not removed during the renovation). In addition, like asbestos abatement, LBP abatement requires strict clearance criteria. If the structure is to be reused as a residence, the clearance should be conducted in accordance with the risk assessment protocol found in 24 CFR Part 35. The developer is required to disclose to the buyer any known locations of LBP. Since most developers want to work with raw land, this process is beyond the intent or scope of this book. However, regulations and guidance on this topic can be found in 24 CFR Part 35, 40 CFR Part 745, and the Guidelines for the Evaluation and Control of Lead-Based Paint Hazards in Housing. These documents can be accessed on the HUD webpage. If LBP remains in a structure after renovation, the location of LBP must be disclosed to the buyer. If the developer intends to reuse structures on a property, it is recommended that an environmental firm be hired to perform the testing and risk assessment and, if LBP is present, design any required LBP abatement and assist with the disclosure requirements.

If a structure is historic (generally defined as being on or eligible for registration on the National or State Register of Historic Places) and is to be included as part of the development, other regulations and requirements will apply; because of their age, most historic structures contain LBP. If this is the case, and the developer is truly interested in restoring a historic structure, it is recommended that the developer immediately hire a knowledgeable historic architect (generally found in a cultural resources firm) and an environmental firm and LBP abatement contractor with specific expertise in renovations of historic structures containing LBP. Historic renovations, especially in those structures containing LBP, have become a specialty expertise in the LBP marketplace, and are beyond the intent and scope of this book.

Underground Storage Tanks (USTs). The wide use of underground storage tanks (USTs) for fuel and waste storage throughout the United States has resulted in significant contamination of our nation's ground water. As of 1988, over 95 percent of the nation's 2 million USTs held petroleum products, and over 54,000 USTs, accounting for nearly 4 percent of the total tank population, were used to store nonpetroleum hazardous substances. Before the advent of fiberglass reinforced plastic (FRP), double-walled vessels, and cathodic-protected construction materials, most USTs were constructed of unprotected, single-wall, bare-steel tanks, which are prone to corrosion and leakage. Older UST systems were typically installed and operated without the proper leak detection, spill and overfill protection, and corrosion-resistant piping. Since there is no comprehensive inventory of all the tank systems installed, there is the possibility that leaking USTs exist on brownfields.

Given the contents of these tanks, releases from USTs can threaten human health and safety, since releases can contaminate soil and drinking water supplies. As of May 2007, more than 468,331 UST releases had been confirmed (www.epa.gov/oust). Leaking USTs continue to pose a serious threat to ground water and drinking water in many parts of the country. Historically, tanks were placed underground to store materials that were hazardous because of their flammability or combustibility. Many tanks were installed underground on the premise that they would never develop leaks.

Until 1984, only state and local regulations covered USTs. In many cases, they covered only the installation, fire safety, and prevention of explosion hazards but did not consider ground water protection. In November 1984, amendments to the Resource Conservation and Recovery Act (RCRA) directed the EPA to establish regulations for monitoring leaks and cleaning up contamination from existing tanks, and to establish standards for the construction and installation of new tanks. The amendments also required tank owners to notify various state agencies of the existence of their tanks. Several factors have combined to highlight the problem of leaking USTs before the public; programs now mandated by the EPA are resulting in more reported release incidents; the ability to detect hydrocarbons in the ground water and soils has greatly increased over the last several years; and lending institutions, property owners, and developers are now realizing the extent of potential liability under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), or Superfund law. Since state and local regulations may differ from the federal requirements, it is important to determine which requirements apply to the USTs in the appropriate state.

Since property that is purchased for development may contain USTs, the purchaser and developer should be aware of the regulatory requirements associated with them. RCRA defines USTs as "any one or a combination of tanks (including underground pipes connected thereto)" which contain a regulated substance and the "volume of which (including the volume of the underground pipes connected thereto) is ten percent or more beneath the surface of the ground." Excluded from the definition are the following:

- Farm or residential tanks with the capacity of 1100 gallons or less, holding motor fuel used for noncommercial purposes
- Tanks storing heating oil used on the premises where it is stored
- Tanks on or above the floor of underground areas, such as basements or tunnels
- Septic tanks and systems for collecting stormwater and wastewater
- Flow-through process tanks
- Emergency spill and overfill tanks

Determining the existence of USTs on an undeveloped tract of land can be a difficult task, since records of installation and use may not exist, as there was historically no requirement to notify state agencies of the existence of USTs. This is one of the reasons why Phase I ESAs are so important for properties planned for development and one of the reasons why there is significant potential liability if initial site assessments are not performed diligently. This assessment should be performed as early as possible in the development planning stage. Ideally it will be performed prior to property acquisition to ensure that any identified environmental concerns can be economically mitigated or controlled during property development. Interviews with past and present owners may reveal that USTs were installed on the property. Searches and reviews of local and state regulatory agency records may reveal that USTs were installed and the installation work was inspected by the local fire marshal, or a leak was investigated by county or state environmental agencies. Historical research into prior land use may indicate that past operations such as farming, quarrying, or air strip landing, which are suspect of potential UST use, occurred at the site. Finally, visual inspection of the property may identify situations or locations that are suspect for the presence of USTs. Visual evidence of the presence of USTs may include vent or fill pipes protruding from the ground, the presence of fill materials such as sand or gravel or other materials not indicative of native soils or geology, mounds of earth with no explanation of origin, evidence of staining, dead or dying vegetation, or hydrocarbon-type odors.

In the absence of historical or visual evidence of the existence of USTs, there are methods of determining the presence of metallic structures that may be USTs. Underground tanks can be found in various sizes, shapes, and construction materials. Metal tanks are usually of welded construction, and some may have some type of exterior coating or protection against corrosion. Newer tanks may be fabricated of fiberglass, epoxy, or other nonmetallic materials. Depth of the tank burial varies; however, the top of the tank is usually not more than one tank diameter below finished grade. Tanks can be found in mounds, partially buried below grade in some installations. If traffic travels over or above the tanks, they may be paved over. Manholes, caps, or other devices to cover or protect tanks and associated piping systems such as fill connections or gauge pipes may be present. Some large tanks may have a manhole to allow access to the tank.

Corrosion is the most common cause of UST leakage for steel tanks and piping. Even as late as the 1970s it was common practice to bury unprotected steel tanks. Surprisingly, studies have indicated little correlation between the product stored in USTs and their corrosion. Yet, soil and ground water conditions can speed the corrosion of USTs. In northern climates, road salt percolates into the soil and ground water and accelerates the corrosion of USTs. Metal failure is frequently observed at connections and pipe fittings. Although mechanical stresses are contributing factors, the most common cause of failure is corrosion from the contact of two dissimilar metals. Overfills, spills, and other accidental releases resulting from oil delivery persons' poor transfer procedures are another major contributing factor to environmental contamination from UST operations. Large releases due to overfill and small releases due to connect-disconnect spillage over a long period of time can be equally serious.

Generally, contamination from USTs leaches into the vadose zone and becomes adsorbed onto clays or forms a thin film on the larger grain-size fraction of soils. Often, if the spill is small, the contaminant remains in the surrounding soils of the UST and remain above the ground water table. Sometimes in very clayey soils the contamination pools under the UST, captured by the clay layer. For large releases, the contamination may migrate to the zone lying immediately above the water table. Depending on the physical properties, such as density, viscosity, and water solubility, the contaminant may sink to the bottom of the ground water aquifer or float on top of the water table. Other factors, such as ground water flow velocity and soil porosity, have a definitive effect on the migration, areal extent, and concentrations of contamination in ground water. For example, denser, less volatile compounds, such as No. 2 diesel fuel, spread more slowly than the more volatile chlorinated solvents like trichloroethylene. Figure 17.3 depicts some of the primary fate and transport mechanisms (Interstate Technology and Regulatory Council, 2005) for two common gasoline-related contaminants (benzene and methyl tertiary butyl ether) following a UST release. The relative significance of the transport mechanism can vary depending on the constituent, as illustrated by the length of the arrows in Figure 17.3.

Typically, investigations of the degree and extent of subsurface contamination from UST leakage begins with a hydrogeologic investigation and sampling survey. Soil borings, sampling, and the installation of ground water wells are well-established techniques that allow direct observation of subsurface contamination conditions. If the contamination is extensive, a more advanced Phase II or remedial investigation and sampling program is required to define the areal extent of subsurface contamination plumes. Upon determination of the extent of contamination, remedial actions and requirements can be selected and implemented. Depending on the extent of contamination, remediation can range from removal of "free" product and related potential source material (Figure 17.4) to more advanced remediation technologies, as discussed in later sections.

Historic Fill. The modestly contaminated fill that underlies many urban and industrial areas (*historic fill*) is one of the most common challenges to brownfields redevelopment. Throughout the early to mid-twentieth century, contractors routinely used wood and coal ash, building demolition material, dredging spoils, and other by-products of industrial activities to fill and grade properties and reclaim land for development, often across wide swaths of cities. Many industries also filled their land with by-products of their operations, such as slag and foundry sand. Thus, historic fill in urban areas is often laced with elevated levels of contaminants such as polycyclic aromatic hydrocarbons (PAHs), heavy metals including lead, and petroleum constituents. The contaminated areas often transcend property bound-

FIGURE 17.3 Underground storage tank release: (*a*) removal of leaking underground storage tank; (*b*) free product released from leaking UST (Courtesy U.S. EPA); (*c*) fate and transport of typical gasoline UST contaminants benzene (B) and MTBE (M). (*Source:* Moyer, E.E., and P.T. Kostecki, eds. 2003. *MTBE Remediation Handbook* Amherst, MA: Amherst Scientific Publishers

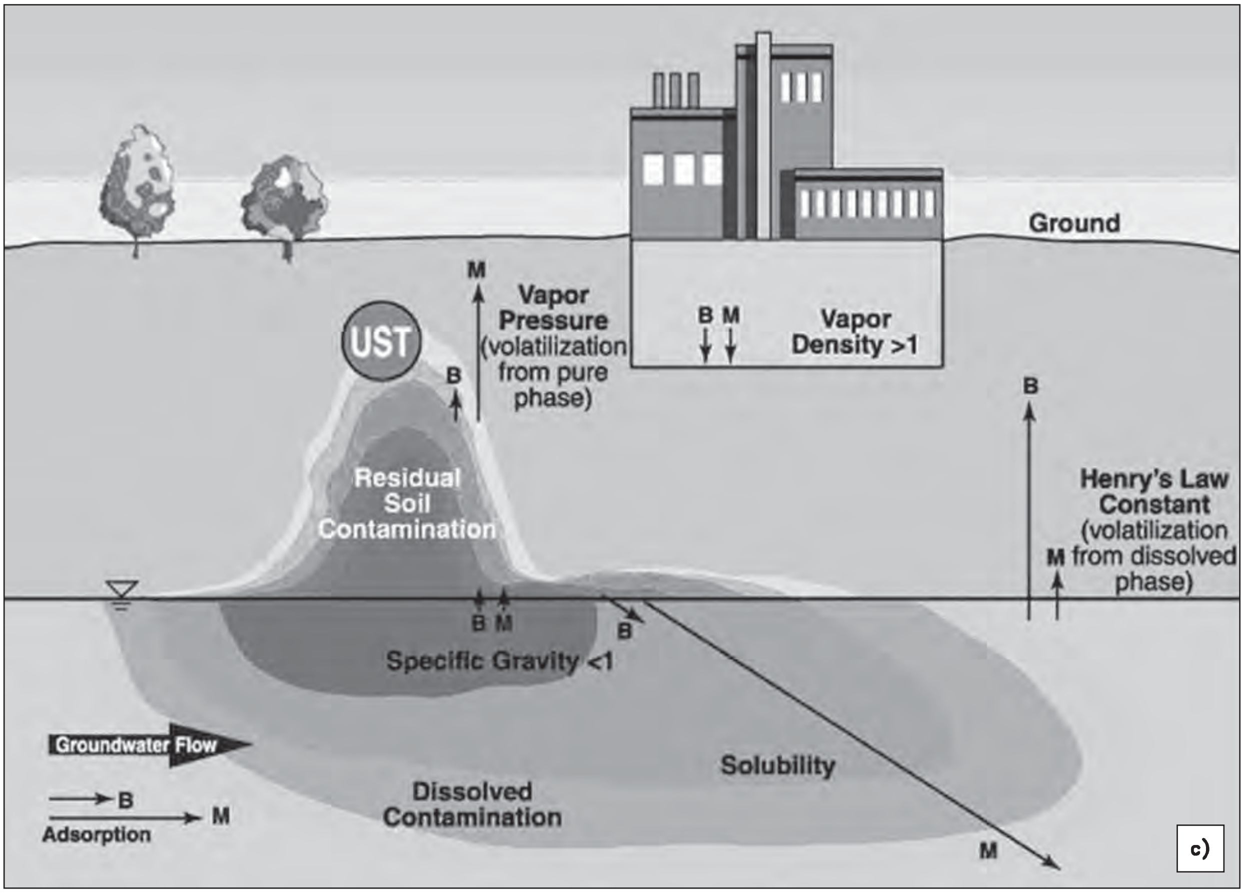

Figure 17.3 (*Continued*)

aries, and sampling of historic fill often reveals contamination that exceeds state reporting thresholds and health-based cleanup standards, but is generally at low concentrations. This low-level contamination typically is relatively uniform and unrelated to any identifiable release or spill.

Brownfields developers and others involved in the remediation of urban properties should be aware of state regulations, guidance, and policies that address the reporting, cleanup, and management issues unique to historic fill, particularly in industrialized states. From the moment the prepurchase environmental assessment begins through the project's final regulatory approvals, it is critical for developers and their advisors to take a strategic approach to historic fill issues in their development plans.

Figure 17.4 Potential source material. (Reprinted with permission from *Pollution Engineering* © 2002)

In some states, flexible policies allow brownfields developers to remediate only those areas of concern that relate to specific releases and to leave historic fill in place or manage it on-site, particularly if the parcel will be restricted to industrial or commercial use in the future. Other states either impose more restrictive requirements on the investigation, cleanup, and management of historic fill or fail to address its presence. Developers should understand the opportunities afforded by those states with flexible historic fill policies and/or manage the challenges posed by sites containing historic fill and associated liabilities in states with more restrictive policies.

A successful strategy for dealing with historic fill may be the difference between a viable and profitable redevelopment and an unsustainable project beset with delays, unanticipated costs, and little chance of completion. To be realistic, development plans and financial projections must take into account the presence of historic fill and the flexibility or lack thereof in state regulations and policies addressing the remediation of contaminants in such material. After remediation and initiation of construction, it is also critical for developers to institute comprehensive but cost-effective fill management plans to comply with regulatory requirements and reuse historic fill on- or off-site where feasible.

Vapor Intrusion

Volatile Organic Compounds (VOCs). Releases of solvents, petroleum hydrocarbons like gasoline, and other volatile organic compounds to soil and ground water can migrate and accumulate in basements, utility vaults, and other low-pressure structures where human exposure may occur.

Vapor intrusion (VI) has received increased attention and evolved rapidly over the last few years as a potential exposure pathway of concern in the investigation and remediation of contaminated sites. The presence of VOCs in soil or ground water offers the potential for chemical vapors to migrate through subsurface soils and along preferential pathways (such as underground utility lines), potentially impacting the indoor air quality of affected buildings. The accumulation of vapors in impacted structures can result in more immediate health concerns associated with high levels of contaminants, as well as the potential for chronic (i.e., long-term) health effects associated with lower levels of site-related contaminants. The objective of a VI study is to determine whether VI of site-related contaminants is occurring and to highlight what actions are appropriate. Volatile chemicals in buried wastes and/or contaminated ground water can emit vapors that may migrate through subsurface solid and into air spaces of overlying buildings. In extreme cases, the vapors may accumulate in dwellings or occupied buildings to levels that may pose near-term safety hazards, acute health effects, or aesthetic problems. In most cases, however, the chemical concentrations are low or, depending on site-specific conditions, vapors may not be present at detectable concentrations.

Methane, generated by biological activity, is commonly encountered in landfills that receive municipal waste or other decomposable organic matter. Houses near landfills have often been threatened by methane in basements or other enclosed areas. Accidents have even occurred at the exposed surfaces of landfills. Methane migration also has the undesirable secondary effect of carrying other gases along with it. Vinyl chloride, which is a microbial breakdown product of the common solvent trichloroethylene, is often present in landfills. Transportation of this gas with methane is particularly alarming because it is a known human carcinogen (cancer causing).

New Jersey, like other states, has developed guidelines for evaluating the potential for vapor intrusion at contaminated sites where buildings either exist or are proposed as part of a new development. The New Jersey Department of Environmental Protection's October 2007 Vapor Intrusion Guidance presents a screening protocol and general investigative procedures to determine whether the concentration of VOCs in soil and/or ground water presents a potential threat to indoor air quality. If contaminants are present in sufficiently high concentrations, and a viable pathway exists to sensitive receptors (i.e., cracked basement walls), then an actual assessment of indoor air quality and identification of mitigation measures may be required. As discussed in the next section, mitigation technologies are not dissimilar to traditional venting and barrier systems used to mitigate another common building air contaminant: radon.

Radon. When considering land development and the sale of new construction, the developer, architect, and builder can face numerous areas of potential liability. High radon levels may breach warranties concerning the habitability of a property or good workmanship. Builders are advised not to include, contractually, any warranties covering radon. All express warranties should be clear and specific, leaving little or no room for interpretation to include radon.

Negligence claims can be made against the developer or builder for failure to use reasonable care when selecting the site for construction. An architect may be sued for negligence in the design of the property. Furthermore, the builder could be found negligent for not alerting buyers to the possible existence of and dangers of a radon gas problem. Additionally, this failure to warn can be interpreted as fraud and/or misrepresentation. It is suggested that builders make specific reference to radon in the context of warning about the dangers of radon exposure. It is then up to the buyers to decide whether they wish to pursue the issue further. Builders can further protect their interests by also stating that buyers cannot make the sale contingent simply on the results of short-term screening.

The EPA has developed a web page for radon, which goes into greater detail about radon issues and should keep readers and developers apprised of new information regarding radon. This web page can be accessed at www.epa.gov/iaq/radon.

Radon is a naturally occurring, colorless, odorless, tasteless gas produced from the radioactive decay of radium, which in turn results, through several intermediate steps, from the radioactive decay of uranium. Radon occurs naturally in geologic formations containing uranium, granite, shale, phosphate, or pitchblende. Since uranium and radium are common elements throughout the entire earth's crust, radon occurs naturally in varying concentrations throughout most soils. In addition, water from underground aquifers or wells may carry radon produced from the surrounding rock. Radon is chemically unreactive, an inert gas. Since radon is not chemically bound or attached to other substances, it can move easily through all gas-permeable materials. Radon and its by-products are a lung cancer risk and may cause genetic damage. Typically, exposures to radon gas occur in confined areas such as buildings and basements where the gas can accumulate. Naturally emitted radon gas is unlikely to accumulate to hazardous concentrations in outdoor air or in the general atmosphere of a development site.

The EPA has set an action level of 4.0 picocuries per liter (pCi/L) for continuous long-term exposure to radon gas.

Additionally, the Radon Abatement Act of 1988: Amendment of Toxic Substance Control Act (15 U.S.C. 2661 et seq. PL 100-551), calls for a long-term national goal for all buildings nationwide to have indoor radon levels as low as the ambient air levels outdoors. When initial short-term testing shows levels above this guideline, EPA suggests a follow-up long-term test.

When planning development at an undeveloped site, it may be difficult to predict whether a potential radon gas problem will exist in the structures that are to be built on the property. In this case, some investigation into the potential for radon in the site geology and neighboring property structures is required. In addition to the EPA website, other sources of information in determining site radon potential include the local or state health departments and the U.S. Geological Survey (USGS). Typically, state health departments maintain a list of reported radon testing results within buildings throughout the area. The county's soil science office may also possess radon gas potential data for the area geology. The USGS develops regional radon potential maps or maps defining geological formations that may be indicative of potential radon gas production. If testing or site investigation confirms the potential for elevated concentrations of radon gas in development and/or new construction, remedial steps or design modifications are usually advised to maintain radon levels below the EPA action level of 4 pCi/L of air.

The most practical approach to vapor intrusion mitigation is to prevent vapors from entering a building. This can be done in a variety of different ways, most involving combinations of techniques. An effective method to prevent vapor intrusion during the cleanup process is to install subsurface depressurization systems at the affected buildings. The two most common types are the subslab depressurization system and the submembrane depressurization system. Subslab depressurization systems are installed in buildings with slab (concrete) floors. Submembrane depressurization systems are installed at buildings with earthen or gravel crawl spaces or floors instead of slabs. A subslab depressurization system consists of PVC piping installed through the slab floor and a fan connected with the piping. When the system is on, the fan applies a vacuum beneath the slab and the vapors in the soil beneath the building are directed outside. With submembrane depressurization systems, an impermeable membrane (such as plastic sheeting) is placed over the earthen or gravel area and the ventilation piping is installed through the membrane. Subsurface depressurization systems are also used throughout the country to prevent naturally occurring radon gas from entering buildings; however, when required for organic vapor intrusion, analysis of site-specific contaminants, structural defects, and soil parameters is required. Subslab and submembrane depressurization systems must operate continuously to be effective. They use little electricity, are relatively quiet, and require little maintenance.

For example, before installing a concrete floor, prepare the subgrade with 4 inches of crushed stone and a plastic membrane. Crawl spaces should be isolated from the rest of the structure and vented to the outside. Major entry routes—plumbing and electrical lines, floor cracks, and so forth—should be sealed with a polyurethane caulk (see Figure 17.5). This sealing process, however, normally reduces levels by only a few picocuries and is more commonly used as a precursor to other mitigation techniques, as opposed to being used alone.

The most common method used today involves a combination of sealing and a subslab depressurization system (see Figure 17.5). In existing buildings, PVC pipe (normally 4-inch) is inserted vertically through the concrete slab into the aggregate layer below. A fan is fitted into the piping network, and the piping exits the building, preferably through

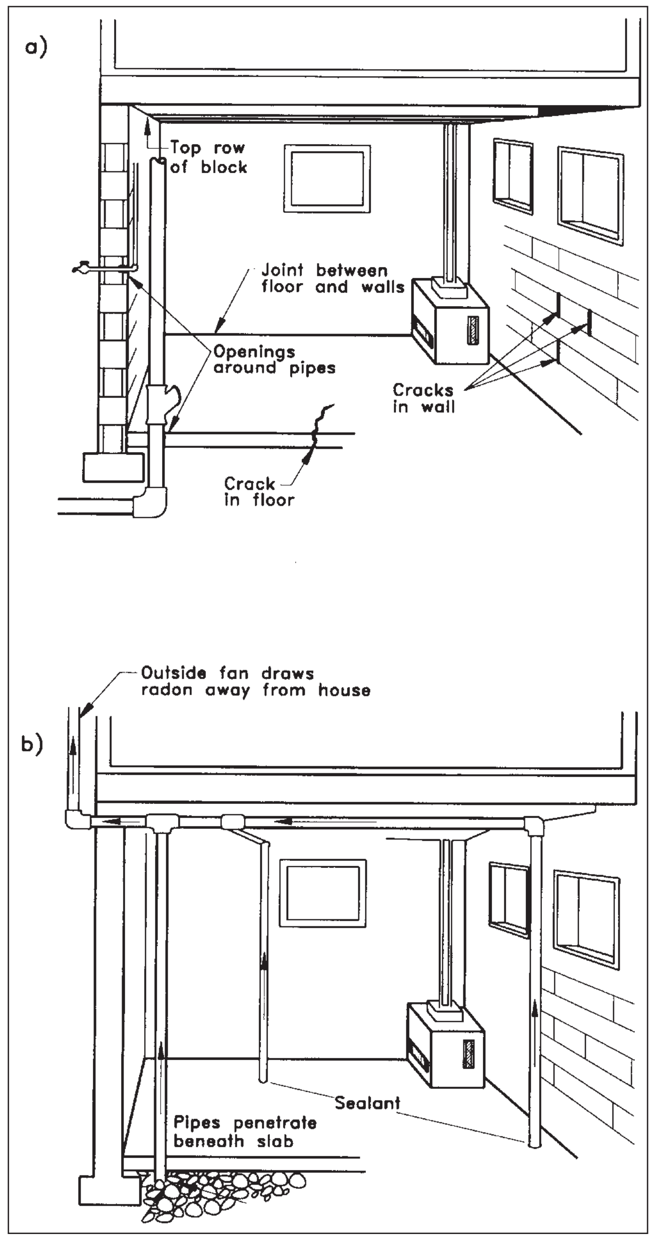

FIGURE 17.5 (*a*) Points of entry of radon into a building; (*b*) subslab depressurization system.

the roof or out the sidewall. Activation of the fan causes soil gas (including radon) to be drawn through the stone under the slab into the piping and is vented outdoors. This method can be modified for use in venting hollow cinder-block walls as well as crawl space areas. Sometimes, it is necessary to reverse the airflow, thereby pressuring the subslab rather than depressurizing. This particular technique has proven to reduce indoor radon levels up to 99 percent.

There are a number of other methods for reducing radon in buildings. Depending on the source or route of entry, a combination of methods such as natural or forced ventilation, drain tile suction, block wall ventilation, or subslab suction may be employed. EPA document OPA-86-005, *Radon Reduction Methods—A Homeowner's Guide,* describes these methods in detail and can be obtained by calling the EPA's hotline at (202) 554-1404 or by accessing EPA's webpage for radon (www.epa.gov/iaq/radon).

Regulatory Issues

Voluntary Cleanup Programs. States began creating brownfield and voluntary cleanup programs (VCPs) in the late 1980s due to the complexity of the Superfund process and the realization that public funding was not sufficient to address all contaminated sites. VCPs allow property owners to voluntarily enter a site into a state regulatory process to complete the cleanup of their property. Through a cooperative agreement, the state and the voluntary party agree to the cleanup approach needed to achieve cleanup levels that are protective of human health and the environment. In the mid-1990s, the EPA formally recognized the benefits of the state brownfield programs and VCPs. All states have since moved to some extent to create similar forms of programs. Upon completion of the cleanup process, the voluntary party receives a no-further-action letter, which provides some degree of environmental closure and clarity of the party's future liability. In most states, the liability protection does not attach to the responsible party who discharged the substance(s) necessitating the cleanup (even if they have done the voluntary cleanup).

Many states differ in the way in which cleanups are implemented and the amount of oversight that is provided. Several states take a traditional regulatory approach, while other states have developed alternative programs. Massachusetts, for instance, was the first state to privatize a portion of the state cleanup program through the use of licensed site professionals (LSPs). This process has placed more of the responsibility and, hence, liability on licensed individuals to document the effectives of cleanup activities.

Overall, state brownfield programs and VCPs have been effective because they foster public-private partnerships to promote redevelopment. Over the last 10 years, the EPA has reported more than 50,000 properties that have been cleaned up using state brownfield programs and VCPs. Most state programs have common definitions of a brownfield, eligibility requirements, financial incentives, and some degree of liability relief. However, it is difficult to compare programs because the details of these components differ greatly from state to state. For example, South Carolina defines brownfields as "real properties, for which the expansion, redevelopment, or reuse may be complicated by the presence or potential presence of a hazardous substances, pollutants, or contaminants" (www.scdhec.gov). On the other hand, Michigan has a more expansive functional definition to include any contaminated or potentially contaminated property with a potential for redevelopment.

To further complicate a comparative analysis, some states have multiple regulatory programs which a brownfield or VCP-eligible site may enter. A VCP may not be the only state oversight program that regulates cleanup activities. Instead, some sites are obligated by law to enter into a nonbrownfield program. For example, in New Jersey, cases are assigned to a specific program based on site type—regulated USTs are entered into the UST program, while sites in brownfield development areas (BDAs) are in the Office of Brownfield Reuse. Illinois, by comparison, allows an owner to choose which program oversees cleanup (for example, a UST site may be entered into either the UST program or the Site Remediation Program). This further complicates comparisons of VCPs within states and between states because each is based on a different array of legislative procedures.

State brownfield programs continue to evolve to meet new challenges, but impediments remain. Developers should be cognizant that the level of environmental liability relief may not be clearly defined in all cases and that lingering third-party liability issues remain. This ambiguity regarding liability results in a number of corporate property owners deciding to hold on to brownfield sites. Additionally, although most states consider planned end use when determining cleanup levels, some, such as New Jersey, do not allow the use of site-specific risk assessments. This causes owners and prospective purchasers to perceive some state cleanup standards as too stringent or inflexible. These impediments create a situation where cleanups may be technically feasible but not economically viable for redevelopment, and result in developers and investors favoring construction on greenfields. Moreover, some state programs suffer from the success of the brownfield market. The increased number of sites seeking to enter VCPs and brownfield programs has put considerable pressure on these programs, which causes slower response times and competition for financial incentives and increases the administrative cost of operating programs.

Site Characterization and Investigation. The purpose of this step is to evaluate the potential for contamination at a particular site by collecting and reviewing existing information. The environmental site assessment (ESA), typically referred to as an ASTM Phase I environmental site assessment, is an initial investigation usually limited to a search of historical records. The data collected includes information about past and current environmental conditions and historical uses of the site. The ESA is the most crucial step in the brownfields process, because any further environmental investigation and cleanup will hinge on whether potential recognized environmental concerns are identified during that phase. As of November 1, 2006, parties must comply with the requirements of the All Appropriate Inquiries Final Rule or follow the standards set forth in the ASTM E1527-05 Phase I environmental site assessment process to satisfy the statutory requirements for conducting all appropriate inquiries. All appropriate inquiries must be conducted in compliance with either of these standards to obtain protection from potential liability under CERCLA as an innocent landowner, a contiguous property owner, or a bona fide prospective purchaser.

The site investigation (SI), also referred to as an ASTM Phase II environmental site assessment, focuses on confirming whether any contamination exists at a brownfield site, and characterizing the nature and extent of that contamination. It is essential that an appropriately detailed study of the site be performed to identify the cause, nature, and extent of contamination and the possible threats to human health or the environment. For brownfield sites, the results of such a study can be used in determining goals for cleanup, quantifying risks, determining acceptable and unacceptable risk, and developing effective cleanup plans that minimize delays or costs in the redevelopment and reuse of property. To ensure that adequate information is obtained to support future decisions, the proposed cleanup measures and the proposed end use of the site should be considered when identifying data needs during the site investigation.

Although each state may have variations in their specific requirements, the site investigation phase may include the analysis of samples of soil and soil gas, ground water, surface water, and sediment. The migration pathways of contaminants also are examined during this phase, and a baseline risk assessment may be needed to calculate risk to human health and the environment. The use of field test kits and real-time analysis equipment is useful during this phase to provide a means for rapid decision making in the field.

The Triad Approach is an EPA-recommended procedure that allows investigators and stakeholders to implement a strategy that is flexible and meets the needs of the site. The Triad Approach includes the use of systematic planning to lower overall project costs and dynamic working strategies to reduce or eliminate the need for multiple mobilizations on a site to reach closeout. For brownfield sites, where decision making is closely tied to economic constraints and public acceptance, increased data quality obtained using real-time measurement equipment coupled with conventional analytical laboratory methods provides stakeholders the confidence needed to make informed decisions.

Remedial Action. Upon delineating and characterizing site impacts and gaining regulatory approval of the investigation findings, a work plan is generally required to identify the remedy for the brownfield site. If no impacts are found to be present, the submission of the investigation report may be accompanied by a request for no further action. If not, it is important to confirm the site-related constituents of concern and associated remedial action objectives for those constituents for all media (soil, ground water, etc.). In many states, such as New Jersey, regulators require an evaluation of potential remedial alternatives for the site. The objective is to select a remedy that is demonstrated to be effective at achieving/ensuring attainment of remedial action objectives, achievable in the field, and cost effective. A critical consideration during the remedial selection phase is the specific end-use and development features anticipated for the brownfield site. In many cases, the most appropriate remedial technology for the site may not be practicable because of the encumbrances it may cause on future utilization of the site. For example, ground water recovery systems coupled with above-grade treatment are well-established approaches; however, if the viability of the redevelopment project depends on maximizing parking or storage capacities, such encroachments on the usable footprint of the site may not be acceptable. Additionally, it is not uncommon to creatively integrate many of the redevelopment features and infrastructure improvements as part of the remedy. Waterfront bulkheads, for example, are often required to fill and raise portions of the site above tidewaters. These bulkheads can often be designed to concurrently serve as an engineering control (barrier) to prevent direct discharge of contaminants to potentially sensitive marine receptors.

Although not exhaustive, the following section describes some of the technologies that are commonly used on brownfield remediation and redevelopment projects.

CHALLENGES AND SOLUTIONS

The challenges that brownfield developers commonly face are related to soil, sediment, or ground water contamination. There are a variety of remediation technologies available to address environmental cleanup requirements prior to, or concurrently with, site redevelopment. The selection of the most appropriate remedy depends on the type and distribution of contaminants, the anticipated end use and design of site features, the regulatory cleanup objectives, and desired cleanup periods. A key element of any remedy is to eliminate the source of the contamination first. Often, this is accomplished following spills or release by rapidly containing and removing the leaking UST, released product pooled on the ground, and so on. On the other hand, petroleum contamination from a UST release that occurred years ago may exist as a separate phase or free product in soil or ground water. Free product can volatilize directly to soil vapor or dissolve in ground water for years without diminishing in size. Therefore, it would neither be cost effective nor generally acceptable from a regulatory standpoint to implement a remedy that treats the vapors entering a building or dissolved contaminants in the ground water without remediating the product source, since the release and migration of contaminants would likely continue indefinitely. Alternatively, soils at a brownfield site that exceed a specified cleanup standard may be ubiquitous in the region with no known source. A properly constructed surface cover (asphaltic pavement, building foundation, etc.) may effectively serve to eliminate the potential human exposure pathway and thereby obviate the need to remove or otherwise remediate the soil.

Remediation Technologies

The following sections present some remedial technologies applicable to contaminants that may be encountered at brownfield sites. Ultimately, the selected technology must achieve remedial objectives and complement, or at least be compatible with, the developed features of the site.

Ground water Pump-and-Treat. Pump-and-treat is one of the oldest and most widely used ground-water remediation technologies. Conventional pumping and treatment involves extraction of ground water from an aquifer and treatment of the water above the ground. The extraction step is usually conducted by pumping ground water from a well or trench. The treatment step can involve a variety of technologies such as adsorption, air stripping, bioremediation, chemical treatment, filtration, ion exchange, metal precipitation, and membrane filtration. Ground water pump-and-treat is effective for providing hydraulic containment and preventing fugitive migration of ground water beyond site boundaries at concentrations that exceed applicable standards; however, because it relies on contaminants to first dissolve in ground water, it is not a cost-effective approach for eliminating the ground water contaminant source. This is particularly true at sites where free or residual product is present. It is not uncommon for ground water pump-and-treat systems to operate for 15 years or more without achieving the desired cleanup objectives. These systems are also energy and labor intensive by nature and, as stated earlier, typically include above-grade enclosures and treatment equipment, which encumber the functionality of a site. For these reasons, they are not preferred as remedies for many brownfield sites.

Soil Vapor Extraction. Soil vapor extraction (SVE), is a well-established remedial technology that reduces concentrations of volatile contaminants adsorbed to soils above the water table. The technology is based on applying negative pressure (vacuum) through wells near the source of contamination in the soil. Volatile components of the contaminant mass "evaporate," and the vapors are drawn toward the extraction wells. Although the primary effect of this technology is in situ, the extracted contaminant vapors must then be treated (typically above ground or ex situ) before being released to the atmosphere. Ex situ treatment is usually accomplished using granular activate carbon (GAC) or thermal oxidation (combustion) equipment. SVE provides a secondary benefit by increasing the flow of fresh air through the subsurface. This increased airflow raises the concentration of oxygen in soil and ground water, which promotes aerobic biodegradation of some contaminants. Thanks to advances in drilling technology, SVE wells can be installed in vertical or horizontal configurations depending on physical site constraints and the location of the contaminant mass. In areas of high ground water levels, water table depression pumps may be required to offset the effect of upwelling induced by the vacuum. Alternatively, the system can be equipped with a more powerful liquid-ring pump to apply negative pressures up to 40 inches of mercury or a supplemental ground water pump to recover both ground water and soil vapor as enhanced recovery. See Figure 17.6.

This technology has been proven effective in reducing concentrations of VOCs and certain semi-VOCs (SVOCs).

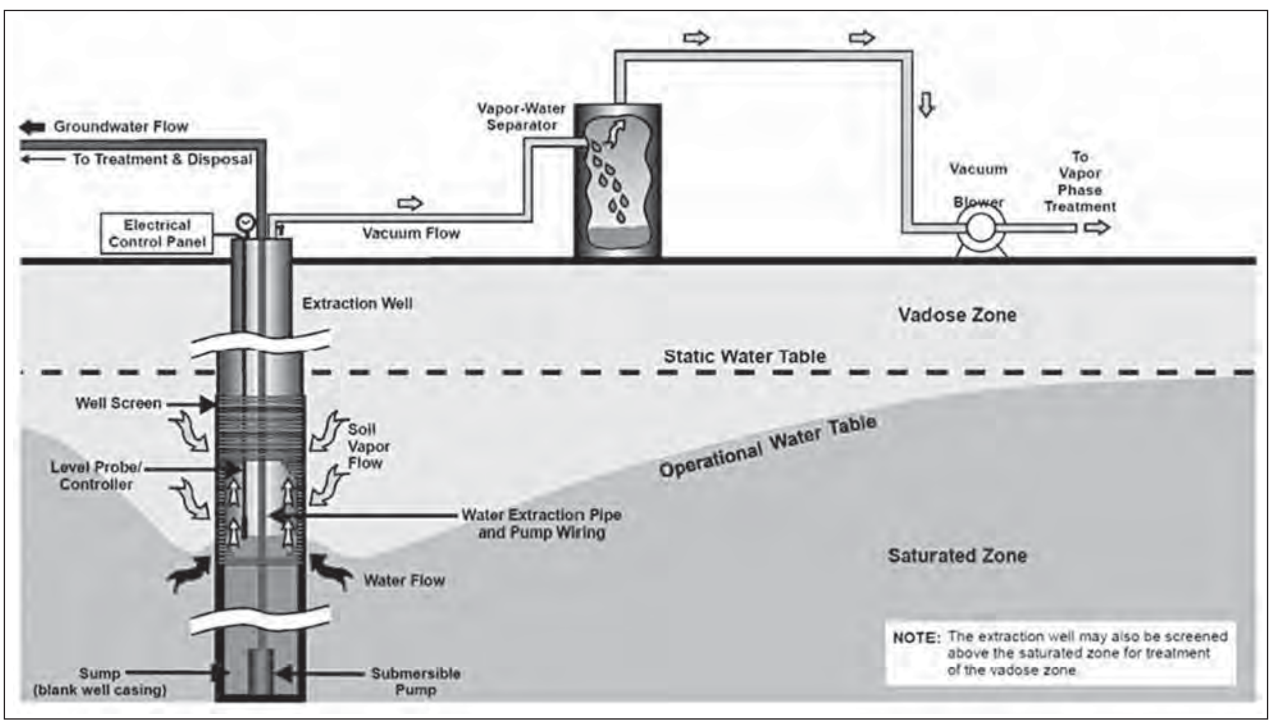

FIGURE 17.6 Typical multiphase extraction. (U.S. EPA. April 1997)

SVE is generally more successful when applied to the lighter (more volatile) petroleum products such as gasoline. Diesel fuel, heating oils, and kerosene, which are less volatile than gasoline, are not readily removed by SVE, nor are lubricating oils, which are nonvolatile. Because almost all petroleum products are biodegradable to a certain degree, these heavier petroleum products may be suitable for removal by bioventing. Injection of heated air also can be used to enhance the volatility of these heavier petroleum products because vapor pressure generally increases with temperature. However, energy requirements for volatility enhancement may be so large as to be economically prohibitive.

SVE is generally not appropriate for sites with a ground water table located less than 3 feet below the land surface. Special considerations must be taken for sites with a ground water table located less than 10 feet below the land surface because ground water upwelling can occur within SVE wells under vacuum pressures, potentially occluding well screens and reducing or eliminating vacuum-induced soil vapor flow. SVE may also be appropriate near a building foundation to prevent vapor migration into the building. Soil structure and stratification are important to SVE effectiveness because they can affect how and where soil vapors will flow within the soil matrix under extraction conditions. High moisture content in soils can reduce soil permeability and, consequently, the effectiveness of SVE by restricting the flow of air through soil pores. Fine-grained soils create a thicker capillary fringe than coarse-grained soils. The radius of influence (ROI), or greatest distance from an extraction well at which a sufficient vacuum and vapor flow can be induced to adequately enhance volatilization and extraction of the contaminants in the soil, is a critical design parameter. This is typically established using site-specific pilot tests. Extraction wells should be placed so that the overlap in their radii of influence completely covers the area of contamination.

Advantages of SVE systems include proven performance, relatively short treatment times (six months to two years under certain conditions), cost competitiveness (approximately \$20 to \$50 per ton of contaminated soil, and that they can be applied at sites with free product and can be combined with other technologies. Disadvantages include diminishing rates of mass removal, as concentration reductions greater than about 90 percent are difficult to achieve; that they are not effective in low-permeability soil or stratified soils; that they usually require costly treatment equipment for recovered vapors, which can also encumber future site operations; and that an air emission permit is generally required.

Air Sparging. Air sparging involves injection of air or oxygen into a contaminated aquifer. Injected air moves horizontally and vertically through the soil column, creating an underground air stripper that removes volatile and semivolatile organic contaminants by volatilization. SVE is usually implemented in conjunction with air sparging to remove the generated vapor-phase contamination from the vadose zone. When used appropriately, air sparging has been found to be effective in reducing concentrations of VOCs found in petroleum products at UST sites. Air sparging has many of the same advantages and disadvantages as SVE with respect to soil type, cost, and applicable contaminant type. Air sparging is generally more applicable to the lighter gasoline constituents (i.e., BTEX) that have Henry's law constants greater than 100 atmospheres and vapor pressures greater than 0.5 mm Hg, because they readily transfer from the dissolved to the gaseous phase. Air sparging is less applicable to diesel fuel and kerosene. Like SVE, air sparging also provides a secondary benefit by raising subsurface oxygen levels, which enhances biodegradation of contaminants below and above the water table. Because air sparging tends to "mound" the water table near the injection site, this technology is generally not acceptable where floating free product is present because this can promote free product migration. Additionally, as stated earlier, air sparging tends to liberate contaminants to the unsaturated zone, where the vapor-phase contaminants could potentially migrate to basements and other low-pressure structures.

Chemical Oxidation. Chemical oxidation is achieved with chemicals that react with petroleum and other hydrocarbons (i.e., chlorinated solvents) to break them down to innocuous compounds. Some examples include potassium permanganate, ozone, hydrogen peroxide, and Fenton's reagent. In contrast to other remedial technologies, contaminant reduction can be seen in short time frames (e.g., weeks or months). A variety of chemical oxidants and application techniques can be used to bring oxidizing materials into contact with subsurface contaminants to remediate the contamination. With sufficient contact time with the organic contaminants, chemical oxidants may be capable of converting the petroleum hydrocarbon mass to carbon dioxide and water. By nature, these materials are dangerous and must be applied by trained personnel. Although potassium permanganate and other oxidants are well known for water treatment applications ex situ, advances in technology have enabled these chemicals to be safely and effectively delivered to the subsurface to remediate contaminants on site (Figure 17.7). The reactions ultimately irreversibly reduce concentrations of petroleum hydrocarbons in soil and ground water. Chemical oxidation technologies are predominantly used to address contaminants in the source area saturated zone and capillary fringe. Cost concerns can preclude the use of chemical oxidation technologies to address large and dilute contaminant plumes. More frequently, chemical oxidation technologies are employed to treat smaller source areas where the petroleum mass is more concentrated. Certain proprietary oxidant formulations such as RegenOx™, manufactured by Regenesis Ltd., are engineered in chemically complex formulas to provide greater stability and longevity in the subsurface, thereby increasing their remedial effectiveness.

Solidification/Stabilization. Solidification/stabilization (S/S) reduces the mobility of contaminants in the environment through both physical and, for certain contaminants, chemical means. The S/S process involves blending contam-

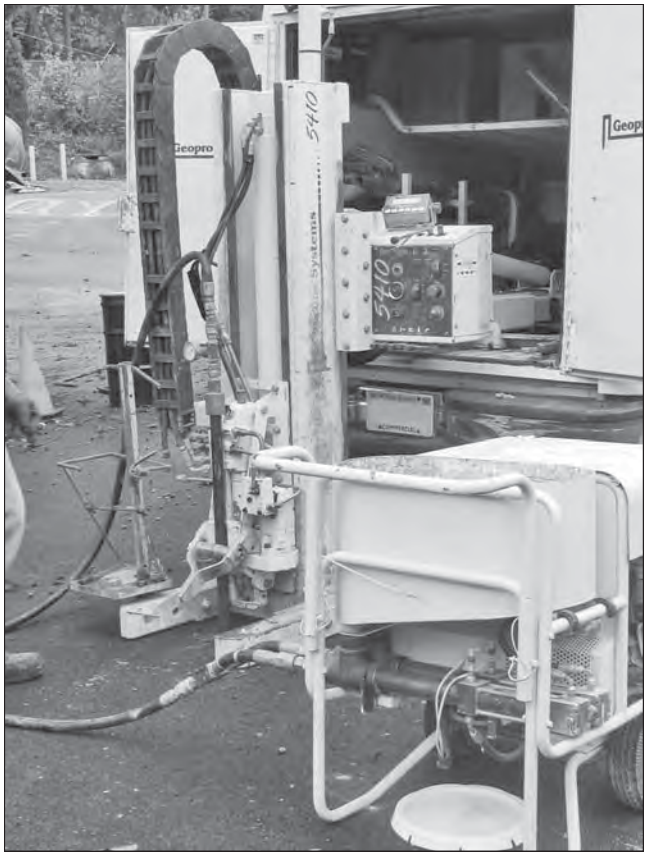

FIGURE 17.7 In situ chemical oxidation. (Photo: David Bausmith © 2007)

inated solids or semisolids with a reagent (typically Portland cement, fly ash, cement kiln dust) to physically bind or enclose contaminants within a stabilized mass. S/S can be performed both ex situ and in situ. Ex situ S/S requires excavation of the material to be treated, and the treated material can either be disposed of or reused on-site. In situ S/S involves use of large-diameter augers or mixing head systems to add binders to contaminated soil or waste without excavation. Although S/S treatment commonly involved Portland cement for treatment of metal-impacted soil, it can be applied to a variety of contaminated media (e.g., soil and sediment) with a variety of contaminants (e.g., heavy metals, PCBs, and organics). S/S treatment has an added benefit for brownfield projects in that soil conditions can be dramatically improved for construction of structures and pavements.

The EPA has identified S/S treatment as a Best Demonstrated Available Treatment Technology (BDAT) for many Resource Conservation and Recovery Act (RCRA) hazardous wastes. According to the EPA, S/S is the most frequently selected treatment technology for controlling the sources of environmental contamination at Superfund program sites. Over 25 percent of selected remedies for these sites include the use of S/S.

There are many advantages to using Portland cement as a S/S binding reagent. First of all, Portland cement is manufactured to specification, which ensures uniformity. Also, its performance is proven and well-documented. Portland cement has been used to treat waste in the United States since the 1950s. Finally, according to the Portland Cement Association (PCA), additional brownfield credits are given for redevelopment of a brownfield site where cement-based S/S is used. The Leadership in Energy & Environmental Design (LEED) program encourages reduction of construction waste, and up to two credits (Materials & Resources Credit 2.1 and 2.2) can be earned by diverting construction, demolition, and land-clearing debris from landfill disposal (Portland Cement Association, 2007, www.cement.org). Through the use of S/S remediation, contaminated soils often can be reused on-site, and reuse of treated soil reduces the quantity of waste disposed of at landfills. See Figure 17.8.

Enhanced or Natural Attenuation. Natural attenuation is a remediation alternative for containment and reduction of the mass and concentration of petroleum hydrocarbons in the environment to protect human health and the environment. The technology takes advantage of the presence of naturally occurring microorganisms in soil and ground water that metabolize or otherwise degrade contaminants. Oftentimes, the microorganisms have been in the presence of the contaminant sufficiently that they have had time to overcome a primary obstacle associated with bioremediation: acclimation to a foreign substrate. Remediation by natural attenuation depends on processes such as biodegradation, dispersion, dilution, volatilization, hydrolysis, and sorption to attenuate petroleum constituents of concern to achieve remediation goals.

In general, remediation by natural attenuation should not be considered a presumptive no-action remedy. A determination of whether remediation by natural attenuation is appropriate for an individual release site, relative to site-specific remedial goals, requires site characterization, assess-

FIGURE 17.8 In situ stabilization/solidification. (Reprinted with permission of *Pollution Engineering* © 2002)

ment of potential risks, evaluation of the need for source area control, and evaluation of potential effectiveness similar to other remedial action technologies. Application and implementation of remediation by natural attenuation requires demonstration of remedial progress and attainment of remedial goals by use of converging lines of evidence obtained through monitoring and evaluation of resulting data. Monitoring of ground water should be conducted until it has been demonstrated that natural attenuation will continue and eventually meet remedial goals.

The primary line of evidence for remediation by natural attenuation is provided by observed reductions in plume geometry and observed reductions in concentrations of the constituents of concern at the site. Secondary lines of evidence for remediation by natural attenuation are provided by geochemical indicators of naturally occurring degradation and estimates of attenuation rates. Additional optional lines of evidence can be provided by microbiological information and further analysis of primary and secondary lines of evidence such as through solute transport modeling or estimates of assimilative capacity.

The basic premise of enhanced natural attenuation is that for some sites, flux reductions achievable by natural attenuation processes may not be sufficient to meet regulatory approval as protective of human health and the environment such that monitored natural attenuation would not be a viable treatment option. Often this occurs because microorganisms simply do not have sufficient electron acceptors (oxygen, nitrate, etc.) or nutrients to metabolize contaminants. One example of a simple enhancement would therefore involve subsurface injection of oxygen and/or nutrients to stimulate natural microbial activity. The distinction between natural and enhanced attenuation is that both typically require an initial step of aggressive, primary treatment for contaminant plume sources. This is an important measure to reduce the source size and plume loading. Following primary treatment, a comparison of plume loading from the residual source and natural attenuation capacity within the plume will determine if the plume is expanding, stable, or shrinking. A stable or shrinking plume raises the possibility that natural attenuation is a potentially appropriate plume management strategy. However, if the plume is expanding (or the natural attenuation processes are not sustainable for a stable or shrinking plume), the option exists for considering introduction of enhancements to reduce plume loading and/or increase the attenuation capacity of the system. If sustainable enhancements can be implemented, then enhanced attenuation becomes a viable treatment approach. If not, an additional phase of aggressive source/plume treatment probably will be required.

Natural or enhanced attenuation is preferred, where appropriate, at brownfield sites because it does not encumber site functionality, results in innocuous end products, and requires little to no maintenance besides regular ground water monitoring. The disadvantages are that attainment of remedial objectives is difficult to predict and ongoing monitoring is required to demonstrate that predicted degradation is occurring.

Engineering and Institutional Controls

Engineering and institutional controls are remedies that are commonly used at brownfield sites and have the effect of limiting activity and use at the site. Although this sounds contrary to earlier statements about the importance of maximizing the functionality of the redeveloped site, the intent of these remedies is to provide administrative and physical controls to prevent unacceptable human exposure to contaminant concentrations that exceed an unrestricted use standard. Examples of engineering controls are pavement soil cover, barrier walls, and security fencing. An institutional control is a deed notice that restricts, for example, how deep a utility contractor could dig into soils before encountering contaminants that exceed the unrestricted use standard. The prevalence of engineering and institutional controls on brownfield projects lies in the fact that relatively low levels of contaminants persist as a result of former industrial operations, and it is impracticable to remediate all contaminants to the unrestricted use standard. However, it is consistent with most regulatory principles to allow contaminants to remain at levels above the unrestricted use standard as long as humans and other receptors are protected from inadvertently being exposed to these contaminants.

Regulatory agencies use activity and use limitations (AULs), often under state VCPs, as a tool for minimizing the risk of exposure to any residual pollutants left on-site by preventing specific uses or activities at a property. Institutional controls (ICs) are legal or regulatory restrictions on a property's use, whereas engineering controls (ECs) are physical mechanisms to restrict site access or use.

Records of IC on a property generally include a description of any contaminants left in place, the risks posed by such contamination, and any restrictions on the property's use. These controls may reside in a number of sources, including deed notices, easements, covenants, and zoning records. An IC may, for example, prohibit the owner from conducting construction activities that could impair the effectiveness of continuing remedial actions on the property or ban specific uses of the property (or ground water). Excavation past a certain depth may also be prohibited by an existing IC to avoid disturbing contaminated soil. ECs take the form of natural barriers, warning signs, fencing, or any other physical structures designed to prevent exposure to hazardous wastes left on a property. It is not unusual for an EC to be used in concert with an IC to physically limit access to a particular part of a property.

ICs are vital elements of response alternatives because they influence and supplement the physical component of the remedy to be implemented. On one hand, the right combination of ICs is necessary to ensure the protectiveness of the remedy and may be critical for obtaining the liability protection; on the other hand, the wrong combination of IC can be a real or perceived impediment to the reuse of a site. ICs provide an added measure of protectiveness at contaminated sites and are not a substitute for thorough investigation and cleanup. The use of ICs must be carefully considered by developers when weighing remedial options, as their use may entail a long-term financial and administrative burden to redevelopers.

Integrated Remediation and Redevelopment

One of the keys to any successful brownfield redevelopment project is the successful marriage of environmental remediation and site planning/engineering. This requires decisive, collaborative decision making on the part of the developer, stakeholders, and technical professionals involved in the project. Brownfields are viewed by many as opportunities for revitalizing urban communities. Redevelopment of brownfield sites may reduce health risks, create jobs, provide services, increase local tax revenues, and improve the overall livability of urban neighborhoods. Brownfield site redevelopment will likely affect communities in different ways, depending on the nature of the land use (e.g., industrial, commercial, residential) and the needs of the community. Left undeveloped, however, brownfield areas remain unproductive, generate little or no economic benefits, and are environmentally and socially detrimental to the surrounding communities. Any brownfield site can be cleaned up and any brownfield site can be developed, but these two activities must proceed with an ultimate land use vision in mind from the start, and this vision must be capable of adjusting to ancillary factors such as financing, stakeholder negotiations, and regulatory priorities.

From an environmental standpoint, thorough site assessments and investigations are critical to ensuring developers have a level of confidence about what problems exist, if any, what remedies are appropriate, and when they can be implemented. From a site-engineering standpoint, critical development features, variance requirements, and so on, must be disseminated for incorporation into the site plans. Although these activities proceed on different tracks, they stand a far better chance of being approved and remaining on schedule if they are coordinated. Environmental regulators are compelled to give favorable consideration to a remediation plan that is consistent with redevelopment features that include public participation in the process. Similarly, preliminary site plans and wetland permits that reflect remediation designs with express approval from regulators are far more likely to be approved.

There are many opportunities to reduce costs and accelerate construction through concurrent activities in addition to those described here. For example, many states, such as New Jersey, have accepted the concept of beneficial soil reuse and the EPA's Area of Contamination (AOC) concept. Through the AOC concept (USEPA, May 25, 1996), the EPA recognizes that certain discrete areas of generally dispersed contamination may be equated to RCRA landfills. Based on this understanding, just as the action of moving hazardous waste within a landfill would not constitute a new act of treatment, storage, or disposal for purposes of the RCRA, the transport of media contaminated by hazardous wastes within a designated area of contamination does not trigger RCRA requirements. Consequently, certain demolition and fill material on a contaminated site may be regraded and consolidated elsewhere at an approved on-site location without triggering costly waste characterization and handling requirements.

FIGURE 17.9 Placement and compaction of stabilized soil as pavement subgrade. (Reprinted with permission of *Pollution Engineering* © 2002)

A good example of a project where redevelopment and remediation were properly coordinated involved a remediation and redevelopment project in Port Newark, New Jersey. One of the remedial action objectives for this former wood-treating brownfield site was to stabilize potential source materials associated with historic wood-treating operations. At the same time, redevelopment requirements for the site called for significant improvements in the site subgrade, as well as raising the grade of the entire 8-acre site an average of approximately 2 feet. The subgrade improvements and

FIGURE 17.10 Asphalt pavement construction. (Reprinted with permission of *Pollution Engineering* © 2002)

Figure 17.11 Final remediated/redeveloped site conditions. (Reprinted with permission of *Pollution Engineering* © 2002)

imported fill required to achieve the site engineering design grades would have required the import of over 6000 cubic yards of structural fill. The majority of the imported fill requirements and subgrade strength improvements were achieved through the implementation of cement-based S/S remedy for the potential contaminated site materials. During S/S activities, the strengthened, stabilized soils increased in volume by approximately 23 percent, which reduced the quantity of imported fill required to achieve final design grades by approximately 5800 CY. Laboratory testing of stabilized soil indicated that the strength of the subgrade was increased to an unconfined compressive strength of 600 pounds per square inch (psi), which far exceeded the minimum requirement of 250 psi. See Figure 17.9.

CONCLUSIONS

When commercial properties in prime locations are left vacant due to environmental impacts, there is significant incentive to redevelop these brownfields and return them to productive use. With increasingly stringent regulations on development of greenfields and growing regulatory and financial incentives, developers are finding new opportunities through brownfields redevelopment. The market for brownfield properties, which are often located in prime locations proximal to waterfront and/or mass transit features, is growing as is the public interest in doing business at these revitalized properties. Brownfields redevelopment requires developers to understand the various environmental and regulatory challenges, and land development professionals to be knowledgeable about implementing effective remedial solutions compatible with site-engineering features that support the end use desired by owners and stakeholders.

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CHAPTER 18

FLOODPLAIN STUDIES

Gilbert R. Jones, PE

INTRODUCTION

Historically, development has occurred near the water, whether it was a navigable stream or a coastline, for recreation or for commerce. Although the benefits of being on the water are numerous, so too are the potential problems created by being so close to something so powerful. Floodplain studies are used to understand and communicate the risk of being near the water. These studies are valuable to a wide variety of users: the building community so they can properly design for and mitigate flood risks, the regulatory community so they can develop proper ordinances and enforce proper building codes, and the public so they can understand the risks of living and working near water bodies.

Changing land use such as developing vacant rural land into residential/commercial use inevitably results in a decrease in pervious surface and an increase in impervious surface. This change in basin imperviousness results in increased degradation of surface water quality, runoff volumes, and flow rates, and, often, the frequency of flooding events. Low-impact development (LID) attempts to minimize this change, but floodplains may still be impacted by new development. In order to accommodate the increased runoff, conventional systems consisting of curb and gutter, storm sewer, ditches, and paved channels are developed to safely convey the runoff through the basin. These systems directly increase flow velocity and decrease the basin time of concentration, resulting in higher peak flow rates.

In a typical moderately developed watershed, the increase in peak discharge could be from two to five times higher than predeveloped conditions. The volume of runoff can be increased by as much as 50 percent, and the time of concentration may be decreased by an even greater percentage. Although such effects from a small individual site may seem inconsequential, the collective effects of numerous sites, throughout the watershed, can have substantial impact on the anticipated flood elevation, especially in the lower reaches of a watershed.

FEMA AND THE NATIONAL FLOOD INSURANCE PROGRAM

History of the NFIP

Historically, the federal government responded to development in and around the floodplain by constructing flood-control projects (dams, levees, and seawalls) and providing emergency disaster relief funding to both communities and individuals. However, this approach did little to discourage unwise development, and in some cases, may have encouraged development in floodprone areas. In response to escalating flood-related losses and the burgeoning cost to taxpayers, in 1968, the U.S. Congress created the National Flood Insurance Program (NFIP). The purpose of the NFIP is to encourage responsible development practices in floodprone areas and to protect property owners through an insurance mechanism that is funded by those whose properties are most at risk of flooding.

The NFIP, first established in 1968 with the passage of the National Flood Insurance Act, was broadened and strengthened by the Flood Disaster Protection Act of 1973, as well as the National Flood Insurance Reform Act of 1994. The NFIP was administered by the Department of Housing and Urban Development (HUD) until 1979, when it was absorbed by the newly created Federal Emergency Management Agency (FEMA). Currently, FEMA administers the NFIP primarily through two of its branches, the Federal Insurance Administration (FIA) and the Mitigation Directorate. The FIA is responsible for administering the insurance aspects of the program, while the Mitigation Directorate is responsible for administering the floodplain management aspects of the program.

The NFIP is a community-based program. A community's participation in the NFIP is voluntary (although some states require participation as part of a statewide floodplain management program). It is the responsibility of each community to assess its flood risks and determine whether they would benefit from the flood insurance and floodplain management assistance provided through the program. At the time of publication, over 20,000 communities participate in the program nationwide.

During the early years of the NFIP, to get as many communities in the program as quickly as possible, FEMA established the Emergency Phase of the program, which was designed to provide limited amounts of insurance coverage at less than actuarial rates. In general, no detailed floodplain studies were conducted for communities in the Emergency Program, and the communities are required to adopt only limited floodplain management ordinances to control future use of its floodplains. Only about 1 percent of the communities participating in the NFIP are in the Emergency Phase.

The remaining participating communities are in the Regular Phase of the NFIP. These communities are generally provided detailed studies of their floodprone areas, and are required to adopt more comprehensive floodplain management ordinances in exchange for higher amounts of flood insurance coverage.

Role of Municipal Governments and Lenders in Floodplain Management under the NFIP

When a community agrees to participate in the NFIP, it receives flood hazard maps prepared by FEMA, and its residents become eligible for flood insurance. In turn, the community agrees to adopt and enforce minimum floodplain management regulations within the Special Flood Hazard Area (SFHA) as depicted on the flood hazard maps. The SFHA is defined as the land area that would be inundated by a flood having a 1 percent chance of occurring in any given year; this flood is referred to as the *base* or *100-year* flood.

The minimum regulations that the community is required to enforce depends on the type of flood hazards present in the community and the level of detail with which the hazards have been studied. At a minimum, a community must ensure that structures are built above the 100-year, or base flood elevation. Other requirements, such as the floodway requirements described here, are specified in Title 44 of the Code of Federal Regulations, Part 60.3.

Generally, obstructions such as buildings or other structures in riverine floodplains inhibit the flow of floodwaters downstream and result in an increase of the upstream flood elevations. Therefore, for many waterways, FEMA has identified a *floodway*. The floodway is composed of the actual stream channel plus the portion of the overbank area that must be kept free from encroachment in order to convey the 1 percent annual chance flood without increasing the base flood elevation (BFE) by more than a specified amount, or *surcharge*. To ensure that development in the floodplain does not result in unacceptable increases in the BFE, as a condition of participating in the NFIP, the community typically adopts the floodway as part of its ordinance and stipulates that no structures be built within it that increase flood elevations. (See Figure 18.1.)

Under the NFIP, the allowable increase, or surcharge, within the floodway is 1 foot; however, many communities and states have adopted more stringent floodway surcharge limits. For example, New Jersey has established a maximum surcharge limit of 0.2 foot, resulting in a floodway that is wider than that needed to convey the 1 percent annual chance flood with a 1.0-foot surcharge. Some conservative communities have even set a zero surcharge limit, effectively defining the entire floodplain as the floodway.

It is important to note that many municipalities have regulations and/or permit requirements governing construction in floodplains that go above and beyond the FEMA NFIP requirements. Therefore, it is important to become thoroughly familiar with the local requirements at the outset of any project that might impact the floodplain.

In addition to the building regulations that local municipalities must enforce, mortgage lenders also have a role to play in floodplain management. Under the NFIP, residential mortgages that are federally backed (almost all are) must have flood insurance if the property is located within the SFHA. Accordingly, all lenders are required to determine prior to approving a mortgage whether the property is in an SFHA and, if so, require the borrower to purchase flood insurance as a condition of the loan.

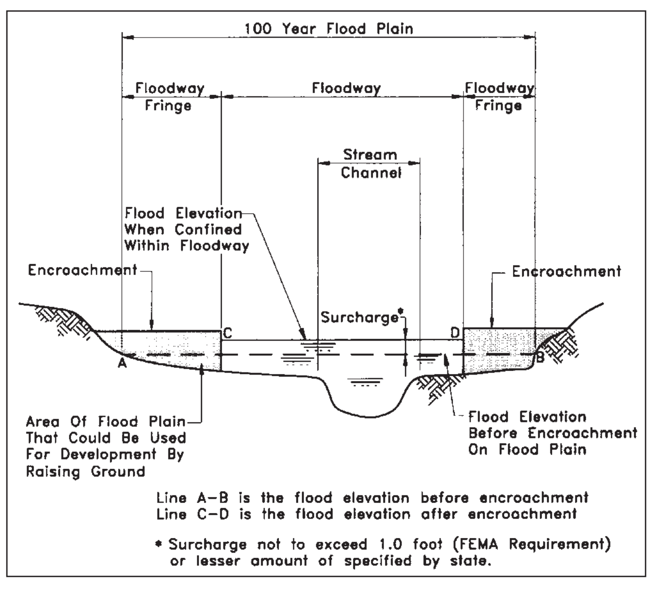

FIGURE 18.1 Floodway schematic showing floodway and a floodway fringe. (FEMA)

TABLE 18.1 FEMA Regional Office Locations

(Above image is from FEMA's website)

FEMA Region I
99 High Street, 6th Floor
Boston, MA 02110
(617) 956-7506

FEMA Region II
26 Federal Plaza, Suite 1337
New York, NY 10278-0002
(212) 680-3600

FEMA Region III
615 Chestnut Street
One Independence Mall, 6th Floor
Philadelphia, PA 19106-4404
(215) 931-5608

FEMA Region IV
3003 Chamblee Tucker Road
Atlanta, GA 30341
(770) 220-5200

FEMA Region V
536 South Clark Street, 6th Floor
Chicago, IL 60605
(312) 408-5500

FEMA Region VI
FRC 800 North Loop 288
Denton, TX 76209-3698
(940) 898-5399

FEMA Region VII
9221 Ward Parkway, Suite 300
Kansas City, MO 64114-3372
(816) 283-7063

FEMA Region VIII
Denver Federal Center
Building 710, Box 25267
Denver, CO 80255-0267
(303) 235-4800

FEMA Region IX
1111 Broadway, Suite 1200
Oakland, CA 94607-4052
(510) 627-7100

FEMA Region X
Federal Regional Center
130 228th Street, SW
Bothell, WA 98021-8627
(425) 487-4600

FEMA Flood Map Products

One of the primary tools in administering the NFIP are the flood hazard maps that identify floodprone areas. Because the NFIP was established as a community-based program, the maps were produced for individual communities. However, since the early 1990s, FEMA has been converting the maps to a countywide format.

FEMA has produced different types of flood hazard maps over the history of the NFIP. During the early years in the program, FEMA produced Flood Hazard Boundary Maps (FHBMs), which show floodplain boundaries based on approximate data and limited analyses. Typically, they were issued during the Emergency Phase of the NFIP, and generally have limited information regarding the floodprone areas. While there are still some communities with FHBMs, most have been replaced with Flood Insurance Rate Maps (FIRMs).

Communities that are in the Regular Phase of the NFIP are provided with FIRMs. FIRMs are generally based on detailed studies of the floodprone areas, and they show more precise information regarding the floodprone areas than the FHBM. (See Figure 18.2.)

To identify the SFHA and other areas on the FIRMs, different zone designations are used. Noncoastal areas within the SFHA are designated as Zone A, AE, AO, AH, A1–A30, or A99. Each of these zone designations represents a different type or risk class of flooding associated with the 1 percent annual chance (100-year) flood. Similarly, for coastal areas, where wave action is a concern, the SFHA is designated as V, VE, or V1–V30. Areas outside the SFHA include Zones B, C, D, and X. Because each zone designation represents a different class of risk, the insurance premium for a property is based on the zone designation.

The floodway is typically shown on a community's FIRM. However, for a period between the mid-1970s and mid-1980s, FEMA did not show floodways on the FIRMS for some communities, but generated separate maps, referred to as Flood Boundary and Floodway Maps (FBFMs), that show only the floodways. As with the FHBMs, FEMA is in the process of phasing out these maps and replacing them with updated Flood Insurance Rate Maps (FIRMs).

Accompanying each FIRM is a report, referred to as the Flood Insurance Study (FIS) report, containing a large amount of supporting information and data such as technical details on how the flood studies were performed, tables containing modeling parameters and results, charts containing floodway information, and graphs showing flood elevation profiles for each stream studied in detail.

Within the past decade, in addition to producing hardcopy flood hazard maps, FEMA has been producing and distributing FIRM data in digital format. Referred to as the *digital FIRM* (*DFIRM*) *database,* it consists of spatial (geographic information system, or GIS) data in several formats, nonspatial data tables, metadata, and a digital copy of the FIS report. The GIS data typically includes:

- SFHA boundaries, floodway boundaries, and base flood elevations
- Transportation data and/or aerial photography
- Stream centerline and coastal shoreline data
- Model cross sections (riverine analyses) and transects (coastal analyses)
- Political boundaries
- Benchmarks
- FIRM panels

FEMA technical standards for all of these products are compiled in FEMA's *Guidelines and Specification for Flood Hazard Mapping Partners.* FEMA's FIRMs and related map products can be obtained from the FEMA Map Service Center (www.msc.fema.gov).

Flood Map Revisions

FEMA's inventory of flood maps contains over 100,000 map panels that cover most of the floodprone areas in the nation. Maintaining these maps is an enormous challenge. Development and other human-induced and natural changes are constantly altering the floodplains throughout all areas of the country. FEMA conducts flood studies routinely in an effort to keep its maps updated. However, given its limited resources and the pace of the changes, FEMA is unable to conduct detailed studies of every area in need. Consequently, FEMA has established several different methods of amending and revising its flood maps, described as follows.

Community- and Property Owner–Initiated Amendments and Revisions

Letter of Map Revision (LOMR). Often, the NFIP maps require revision to reflect alterations to the floodplain caused by construction or improvements (bridge, channelization, culvert, retention pond, etc.), to map previously unmapped floodplains, or to reflect newer or better data (e.g., newer topographic data). A community may request that the maps be revised to reflect such changes by providing technical data to support the revision. If the changes are not extensive enough to warrant republishing of entire map panels, a LOMR may be issued. A LOMR is a form letter that describes the change and contains an attachment showing the revised area. Because the community must adopt changes and revisions to the maps in its local floodplain ordinances, all such LOMR requests must be submitted by, or come with the approval of, the community CEO. If a project is proposed that will impact the flood data on the FIRMs, but it has not yet been built, a conditional LOMR (CLOMR) may be requested. A CLOMR is simply a letter from FEMA stating whether a project, if built as proposed, will warrant a revision to the map. Some municipalities require a CLOMR to

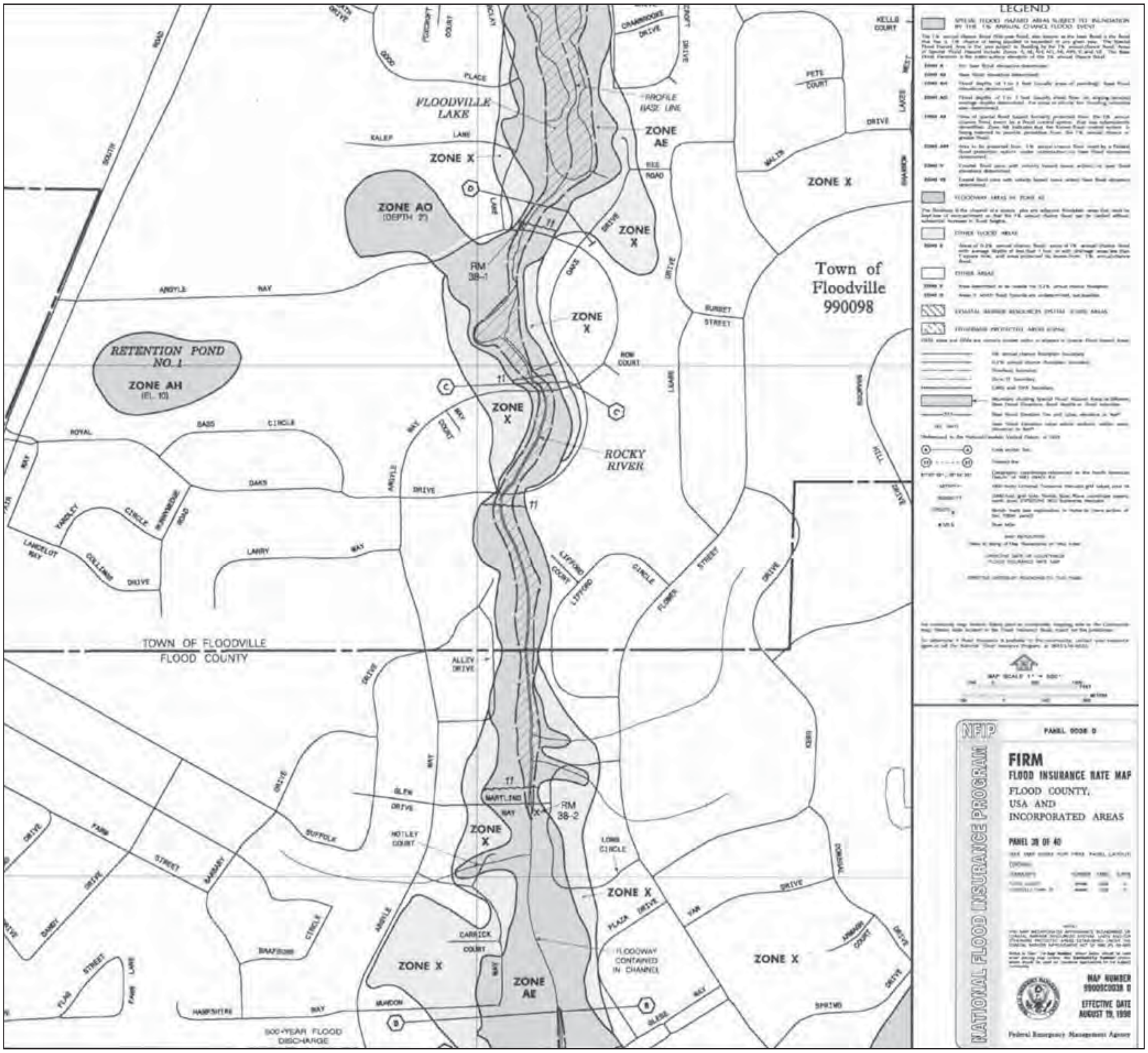

Figure 18.2 Sample flood insurance rate map. (FEMA)

be obtained prior to approval of the project to ensure the changes to the FEMA technical requirements can be met and the maps can be approved via a LOMR once the project is complete.

Letters of Map Amendment (LOMA) and Letters of Map Revision Based on Fill (LOMR-F). Although NFIP maps are prepared using the best available topographic maps at the time they are prepared, due to limitations of scale and topographic definition a property may appear to be in an SFHA even though it is actually above the 100-year flood elevation. If no fill[1] has been used to elevate the property or structure, the property owner or lessee may submit a request to FEMA for a LOMA. A LOMA is a letter from FEMA stating that the property/structure is not in the SFHA.

To obtain a LOMA, the requestor must submit to FEMA a survey or topographic data certified by a registered land surveyor or professional engineer that the lowest ground elevation adjacent to the structure (*lowest adjacent grade,* or LAG) or lowest elevation on the property is above the BFE. If the property is located in an SFHA for which no BFEs have been determined (e.g., floodplains designated as Zone A), then FEMA will assist the requestor in calculating the BFE for that location. Upon review and acceptance of the data, FEMA will issue a LOMA that officially removes the property or structure from the SFHA.

[1]*Fill* is defined to include any earthen material used to raise the ground elevation and includes both structural and nonstructural fill.

If a property is located within the boundaries of an SFHA but has been elevated above the BFE by fill, the property owner may submit certified survey or topographic data to FEMA to request a LOMR-F removing the property from the SFHA. The submission must show that both the LAG and the lowest floor (including basement/crawl space) are above the BFE. Fill used for structural support must meet specific engineering criteria for erosion, stability, and compaction. LOMR-Fs are not permitted in coastal SFHAs designated as V-Zones.

It is important to note that the FEMA maps are not revised or republished when a LOMA or LOMR-F is issued, and these letters do not affect the SFHA delineation or any other features of the NFIP map. Unlike LOMRs, LOMAs and LOMR-Fs are simply letters stating whether a given property is in or out of the SFHA. When issued, LOMAs and LOMR-Fs are sent to the requestor, and a copy is sent to the local community. Copies of all LOMRs, CLOMRs, LOMAs, and LOMR-Fs can be obtained from FEMA's Map Service Center (www.msc.fema.gov).

Studies and Restudies

When new FIRMs need to be created, or updates are warranted that are too large to be done through the LOMR process (e.g., greater than one panel), FEMA will perform a new flood study. FEMA's flood study process consists of a number of major tasks:

- *Scoping:* FEMA, the community, and other key stakeholders meet to plan the flood study.
- *Data collection:* The collection of topographic, planimetric, engineering, and other required data.
- *Engineering analysis:* Hydrologic and hydraulic analyses using state-of-the-art computer models.
- *FIRM production:* Production of maps and associated products, including the FIS report and DFIRM database.
- *Preliminary issuance and appeal period:* FEMA issues draft, or "preliminary" maps to the community and holds a 90-day appeal period during which the public may appeal or protest the maps.
- *Compliance period and final issuance:* Upon resolution of any appeals or protests, the community is given six months to update its local ordinances to reference the new/updated maps. At the end of this six-month period, the maps become the final effective FIRMs for the community.

Traditionally, FEMA used its own contractors to perform flood studies. However, recently, in addition to using its own contractors, FEMA has been partnering with states and large municipalities that have the technical capabilities to assist FEMA with the creation or update of the FIRMs. Under FEMA's Cooperating Technical Partner (CTP) program, a state or community enters into a written agreement with FEMA that specifies the tasks it is responsible for, as well as funding and schedule requirements. A CTP's level of participation can vary, with its contributions ranging from performing a very limited role, such as assisting in collecting existing data, to performing all aspects of the FIRM creation/update process.

Acceptable Flood Study Methodologies

To ensure that the studies and restudies meet the minimum standards required by FEMA, certain technical methods have been reviewed and accepted by FEMA. These methods include hydrologic and hydraulic models and computation methods used in the detailed engineering analyses conducted as part of most studies/restudies (see Appendix G for a full table of accepted FEMA numerical models). Because FEMA occasionally reviews and approves new models and methods and updates existing models and methods, FEMA's website (www.fema.gov/plan/prevent/fhm/en_modl.shtm) should be consulted to obtain the most up-to-date list of approved models.

When performing a flood study, be aware that some communities have more stringent requirements than FEMA and/or require specific technical methods as a result of local conditions. Therefore, it is imperative that anyone performing a flood study be familiar with local regulations and policies.

PREPARING A FLOODPLAIN STUDY

Introduction

A floodplain study graphically depicts an engineering estimate of the water surface elevation expected along a length of a stream for some specified design storm. Typically, floodplain studies are conducted as a design tool as well as a regulatory requirement. As a design tool, they are often used to determine the limits of inundation, for some specified recurrence interval, to be assured that new developments will lie beyond the floodplain. Similarly, they may be used to evaluate the changes in flood elevations due to changes or additions to structures within the floodplain. A floodplain study may also be conducted to evaluate the effectiveness of channel improvements or modifications.

Even if a floodplain study is not necessary for design, it is often a regulatory requirement. It is common for local or state governments to require that a floodplain study be performed and submitted in support of a land development plan. Regulations often contain a provision that a floodplain study is required for a reach of stream if the drainage area is greater than some minimum value (100 acres may be typical). It is common to require a floodplain study to ensure that new construction does not increase the water surface elevation more than the allowable surcharge above the base flood elevation.

Planning a Flood Study

The first step in any flood study is to determine the limits of the stream to be studied. The limits are determined based on the desired results of the study. If the reason for performing a floodplain study is due to a regulatory requirement related to the land development project, the municipality may require the entire length of stream through, and possibly beyond, the project limits to be studied. If the reason for performing the study is to determine the floodplain boundary in a specific location, or to determine the necessity for channel improvements and so on, then the limits of study must be determined such that the portion of the stream impacting the development is studied.

Also, the desired precision of the results must be determined. This specifies the accuracy of the topographic data needed to map the floodplain, as well as the hydrologic and hydraulic methods used for the study. As expected, higher accuracy generally comes at a higher price, since more detailed hydrologic and hydraulic methods can cost orders of magnitude more than simpler methods.

The appropriate recurrence interval(s) must be determined in order to provide the level of risk or protection desired. The 100-year floodplain is the most common for analysis, because of regulatory requirements from local jurisdictions and from FEMA.

Data Acquisition

Before beginning a floodplain study, an information search should be conducted to determine whether previous studies on the subject stream exist or if other studies have been performed in close proximity that may provide some of the data needed for the study. Some federal agencies perform floodplain studies as an aid in identifying floodprone areas. These agencies include the U.S. Geological Survey (USGS), the U.S. Army Corps of Engineers, and FEMA. In addition, some local or state organizations may have drainage plans or floodplain studies already established. If a development project is near a previously or concurrently developed site that is also affected by the subject stream, a floodplain study may have been developed in conjunction with the nearby development. These studies should be identified and examined to determine whether they may be used outright or if some pieces of information might be useful.

When performing a new study, a large amount of data is required. Much of this data may have already been created for other purposes, and it is simply a matter of collecting it. Types of data that are typically collected include:

- Topographic data and aerial photographs for the entire study area
- Hydrologic data such as stream gage data, and, if detailed hydrologic modeling is required, rainfall data, soil types, and land use coverages
- Plans/information for structures in the floodplain, such as bridges and culverts
- Transportation and planimetric data layers to serve as reference features on floodplain maps
- Supplemental field survey at critical cross sections
- Photographs or other field verification of Manning's *n*-values

Topographic and aerial photographic data is often available from local and state agencies, the USGS, and land development project plans. Topographic mapping and aerial photographs should cover the area to be studied, with plenty of additional coverage beyond the actual floodplain limits.

Commonly, hydrologic data is obtained from the USGS, although local and state agencies, particularly engineering departments, frequently maintain this type of data as well. Bridge and culvert as-built plans can sometimes be obtained from state departments of transportation or local public works departments. If not available from these sources, it may be necessary to have survey crews collect this information as part of their field work.

Last, many states and local communities have GIS departments where digital planimetric data can be obtained, such as transportation, parcel, and corporate limit data layers.

Hydrologic Analysis

A hydrologic analysis is performed in order to estimate the flood discharge at a location along the flooding source. The first step in performing a hydrologic analysis should be to determine whether there is a stream gage on the stream in question. If a stream gage is available, a statistical analysis of the gage data generally provides the best estimate of the design storm discharge.

Often in the land development process, however, the drainage areas of the flooding sources in question are relatively small (less than 1 square mile) and not gaged. In trying to determine the flood discharge for an ungaged stream, several techniques can be employed. Often, more than one technique will be utilized in order to support the results. These techniques can be broken down into two categories: regression equations and rainfall-runoff modeling. Federal, state, and local ordinances should be consulted to determine which technique is approved for use in your jurisdiction.

Regression Equations. The land development engineer should once again determine whether any federal, state, or local agency has established flood discharges previously for the ungaged stream under consideration or check the FEMA effective Flood Insurance Study. In the absence of such an analysis, the land development engineer can use the regression equations presented in the most recent regional flood flow frequency report, published by the USGS. These reports are generally available on a statewide basis and provide simple equations that frequently require only a few easily obtainable parameters, such as watershed area and mean annual precipitation. Caution should be exercised when applying these equations, for there are limitations on the size and condition of the watershed to which they are applicable, and they typically have a wide range of standard errors.

Rainfall-Runoff Modeling. Where USGS regional flood flow frequency reports have not been developed or are not applicable because of either rapid watershed development, storage, or stream regulation, the land development engineer can develop a rainfall-runoff model using models such as HEC-HMS or TR-20. These programs as well as the procedures for developing these models have been described in Chapters 21 and 22.

Regardless of method, incremental changes to the flow discharges may need to be calculated along the stream reach, particularly for large project areas where the discharge changes significantly from the upstream limit to the downstream limit. This occurs where tributaries or storm sewers discharge, or where the drainage area increases significantly, within the project area.

Hydraulic Analysis

The basic data necessary to perform the required hydraulic analysis includes study limits, topographic mapping, flow discharges (determined from hydrologic analysis, as discussed), cross sections, and Manning's *n* values. Once the study limits have been determined, some additional distance upstream and downstream should also be included in the study to ensure that the appropriate reach is covered and to account for downstream and upstream impacts. The topographic mapping should be used to lay out the limits and to investigate the stream upstream and downstream of the section to be modeled. The limits should be set such that no hydraulic control sections in the floodplain occur near the limits, such as a severe constriction, a bridge, or a weir, that will have a significant impact on the reach being modeled.

Flood elevations for riverine areas are normally determined by step-backwater computation models, such as HEC-RAS, WSPRO, or WSP-2. The most common is the USACE HEC-RAS program, although the land development engineer should consult the local regulations to determine which of these programs is acceptable for use.

Step-backwater models compute results such as flood depth, width, and velocity at cross sections placed intermittently along the stream. These results are then interpolated between the cross sections. The selection of cross section locations is therefore a very important step in setting up a floodplain model. The topographic map should be used in conjunction with field information to determine the best locations for cross sections. Cross sections should be located at points along the stream where the shape of the section changes, where the slope of the stream changes, at bends in the stream, and at locations where the floodplain conditions otherwise change from the conditions up- or downstream. Consideration should be taken of the entire floodplain, not just the channel portion, when locating cross sections. In addition, cross sections should be located up- and downstream of bridges and culverts and downstream of tributary inflows where the cumulative flow should be adjusted. Cross sections should also be placed at locations where conditions might change due to the land development project, or at locations where floodplain elevations are desired for a specific purpose. Note that local regulations may dictate a maximum allowable distance between cross sections for a floodplain study.

At each cross-section location, the cross-section geometry is required. This may be determined from a topographic map, if the map provides an acceptable level of detail for the study. Often, field surveys will be required to obtain the cross-section geometry necessary for a floodplain study. Using a greater number of cross sections increases the level of detail of the study, but also increases costs for data collection and modeling. Also, a greater level of detail in cross sections may be unwarranted if other aspects of the study have a greater level of uncertainty. For example, increasing the number of cross sections won't improve the results if the flow discharges are questionable. Therefore, considerable judgment must be used in selecting cross-section locations.

Roughness coefficients must be determined for each reach of stream. Most floodplain models use Manning's *n* values to estimate the roughness of the stream channel and overbanks. Selection of *n* values is very important because of the influence of roughness on water surface elevations. Furthermore, *n* value selection is the one parameter that cannot simply be measured in the field but instead must be determined largely from engineering judgment. Proper selection of *n* values provides a greater level of confidence in the floodplain model. Manning's *n* values for several types of channels are presented in Table 18.2.

With the advent of GIS, many hydraulic and hydrologic models' steps are done in an automated or semiautomated manner. Many popular hydrologic and hydraulic models have been GIS-enabled, including the USACE HEC-HMS and HEC-RAS models. GIS allows users to collect, view, and process spatial data, including the input and output model parameters. It allows the results of these models to be mapped using digital elevation models (DEMs), as well as permitting the use of a wide variety of visualization tools. Many communities have GIS capabilities, which allow floodplain data results to be combined with a wide variety of local data sets, such as tax and parcel data and permitting data.

Special Considerations

The preceding discussion applies primarily to floodplain analysis for typical riverine situations. While this covers the most common floodplain study situation, floodplains also exist in coastal areas that require the use of other specialized models and methodologies. Similarly, other special situations, such as ice jams, closed basin lakes, and alluvial fans also require very specialized models and methods. These situations are outside the scope of this handbook. If a project is in a coastal area or involves other special considerations, it is recommended that the local authorities and FEMA be consulted on the accepted methods for evaluating and mapping these flood hazards.

TABLE 18.2 Values of the Roughness Coefficient n

Type of channel and description	Minimum	Normal	Maximum
Excavated or dredged			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
Natural streams			
1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2. Floodplains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
3. Major streams (top width at flood stage >100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	—	0.060
b. Irregular and rough section	0.035	—	0.100

Source: Courtesy of Chow, V.T. 1959. *Open-Channel Hydraulics*. New York: McGraw-Hill. Reproduced with permission of McGraw-Hill, Inc.

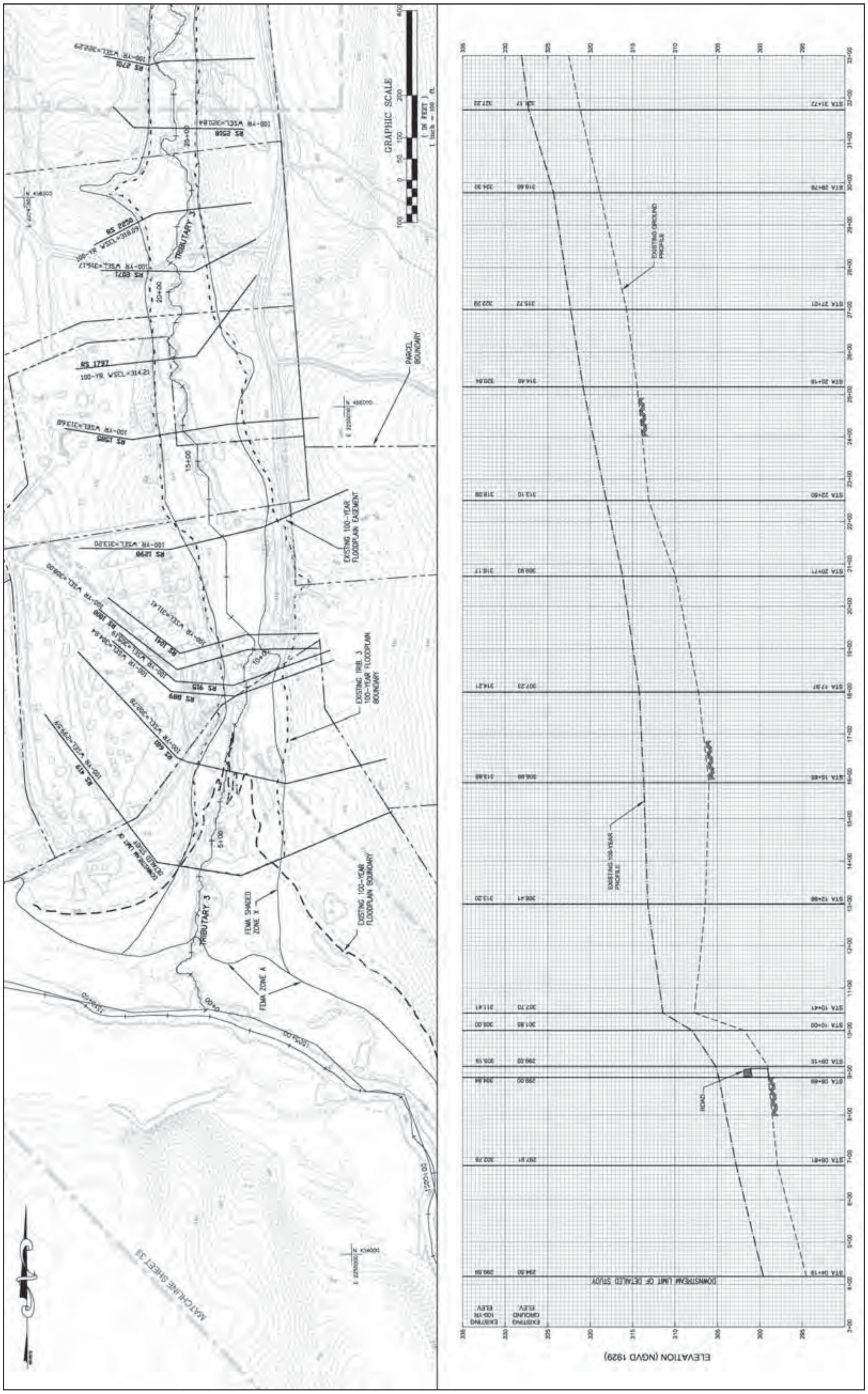

FIGURE 18.3 Typical plan and profile sheet for a floodplain study.

Preparation of Deliverables

While the final deliverables for a flood study are dictated by the needs of the project and client, common flood study products include: (1) a plan view of the stream being studied, usually on a topographic base, with the floodplain boundaries delineated along the stream; (2) a profile (longitudinal cross section) of the stream, with the stream invert elevations and flood elevations delineated; (3) technical documentation regarding the determination of the floodplain elevations and limits; and (4) professional certification of base mapping or survey. This documentation may include calculations and/or computer modeling inputs, parameters and results, a written description of the methods used, sources of data, special or unusual items that affected the modeling, assumptions made, and limitations of the model.

Figure 18.3 shows a typical plan and profile sheet for a flood study. If a floodplain study is prepared to determine and document the changes to flood elevations or floodplain boundaries due to a development project, both predeveloped and postdeveloped floodplains should be presented. If a floodway is required, the floodway boundaries should also be presented. A typical plan and profile sheet of a floodplain study should include the following information: cross-section location, orientation, and numbering; floodplain and floodway boundaries; water surface profiles; water surface elevations; locations of bridges and culverts; locations of incoming tributaries; floodplain tie-in to existing floodplains on tributaries; and location and elevation of any critical structures within or near the floodplain.

If the flood study is to be submitted as a request to FEMA to revise an FIRM (e.g., a LOMR), there are specific forms that are also required. These forms, referred to as MT-2 forms, can be found on the FEMA website (www.fema.gov/plan/prevent/fhm/frm_form.shtm). Also, if a flood study is done for FEMA or its partners for the purposes of creating or revising a FIRM, it must comply with FEMA's *Guidelines and Specifications for Flood Hazard Mapping Partners* (www.fema.gov/plan/prevent/fhm/gs_main.shtm).

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CHAPTER 19

PRELIMINARY ENGINEERING AND HYDROLOGIC ANALYSIS

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INTRODUCTION

Preliminary engineering is an integral component of schematic design, the third step in the land development design process. Schematic design normally occurs after the completion of feasibility and site analysis (step 1) and conceptual design (step 2). At the conclusion of schematic design, the engineer is ready to initiate the last stage of the design process, which is final design. This chapter focuses on the preliminary engineering tasks associated with the development of the schematic design.

Preliminary engineering involves the refinement and development of the information obtained in the previous two steps in the design process. This refinement ordinarily leads to the creation of a deliverable often in the form of a graphic, such as a site plan or a general development plan, but it may include accompanying narrative reports, checklists, estimates, and so on, for review by the developer/builder and local governing agencies. Generally, preliminary engineering is performed by civil engineers; however, planners, architects, landscape architects, the developer/builder, environmental scientists, and reviewers at the local governing agencies, as well as citizens, may be contributors or stakeholders in this process.

The preliminary engineering stage of the design process includes an engineering review of the conceptual design, feasibility, and site analysis. During the earlier design stages, the development program was determined, pertinent information gathered, the site analyzed with all opportunities and constraints presented, and a conceptual site design prepared. At this stage it is time to fine-tune the site design by refining the previous assumptions, performing preliminary engineering analyses and evaluations, and validating the previous assumptions. This is especially important if there are specific, measurable development objectives that are to be achieved in the design such as LEED certification, other third-party green building certification, or (enhanced) compliance with specific regulatory requirements.

Although preliminary engineering often requires a specific level of design detail necessary for review and approval by local governing agencies, a preliminary engineering deliverable is not always required. In many cases, the developer/builder typically requires this level of detail prior to incurring the costs associated with developing the final design. The deliverables produced during the preliminary engineering phase represent a final check of the development program before proceeding with the more detailed final engineering design. Oftentimes, the developer/builder will utilize the information prepared in the preliminary engineering phase to prepare initial construction cost estimates in order to ensure the final design is achievable as originally envisioned or to identify adjustments to the design that must be made to meet project budget constraints. This provides not only the developer/builder and/or local governing review agencies, but also citizens, with a greater sense of comfort about the feasibility and construction costs associated with the proposed development program.

At this stage, the developer/builder might be the owner of the property or the contract purchaser with contingencies or options built into the contract pending the obtaining of an approved rezoning or other related regulatory approvals. Other contingencies may include a specific lot yield, development density, green building rating, or desired gross floor area of a building.

It is important to understand that the development program is always subject to change, particularly when it is presented to citizens and/or public review agencies or when a developer is faced with meeting budget constraints. Hence, the preliminary engineering phase of the design process is oftentimes an evolutionary and iterative process that can last for months or even years as the development approval process (namely, rezoning or entitlement) progresses. For instance, it is not uncommon for changes to the site grading and layout to occur as a result of comments from regulatory agencies or citizens requesting additional open-space and tree preservation areas.

COMPONENTS OF A PRELIMINARY ENGINEERING STUDY

Although the level of detail required in a preliminary engineering study may vary, depending on the developer/builder's needs or the submission requirements of the local governing jurisdiction, certain items are ordinarily required.

A comprehensive base map is an essential part of the preliminary engineering analysis. Ideally, this map includes field-run topographic survey information and site boundary, as well as the location of any existing structures and other physical features of the site. The base map should also include the site opportunities such as buildable areas and natural site amenities and the site constraints such as wetlands, floodplains, mature trees, and environmental corridors. For purposes of schematic-level design, these items should be field-surveyed or at least tied down to the boundary survey. It is important that any demolition requirements be addressed, as well, with the base map.

The focus areas for a comprehensive preliminary engineering study are identical to those that will be performed during final engineering; the difference is in the level of detail. Whereas final engineering documents are more polished and can be used for construction, the preliminary engineering documents are refined enough to minimize problems when preparing the final documents for construction. The following sections of this chapter present a detailed look at each of the components of a preliminary engineering study.

Site Layout and Roadway Design

The first step in developing the preliminary engineering plans for a schematic design is to formalize the conceptual design layout into a geometrically accurate layout. This layout may include the horizontal alignment and configuration of roadways and lot layout in the case of a subdivision plan or arrangement of buildings and parking areas in the case of a site plan. Widths of proposed pavements should be developed based on expected traffic volumes determined from completed traffic studies, or as local requirements may dictate. Curbs, gutters, and sidewalks should also be depicted as appropriate and site access to adjacent roadways illustrated, including any provisions for pedestrian and/or bicycle access improvements or signalization that may be warranted. The preliminary layout should be tied down to the site boundary and lots and/or land divisions should be computed and checked for geometric accuracy. Building setbacks should be established and building envelopes represented. All proposed on-site and off-site improvements should be shown, including easements necessary for utilities and ingress-egress (access).

It is important not to forget that every site layout requires the designer to think in three dimensions. In other words, one should not lose sight of the fact that elevations vary across the layout and the vertical component of the design must be considered when developing the horizontal site geometry. Oftentimes, this becomes an iterative process where the conceptual layout is refined based on existing and proposed site elevations that must be taken into consideration. Part of this refinement can be accomplished by development of profiles of roadways and major site circulation elements. Several computer-aided design and drafting (CADD) software packages allow profiles to be generated fairly quickly based on proposed roadway alignments sampled from a three-dimensional digital terrain model (DTM) of the site topography. Development of roadway profiles allows preparation of a proposed profile with vertical geometric accuracy. They also provide a means to evaluate sight distance and initial analysis of cut/fill requirements.

Once profiles have been developed, typical cross sections for roadways can be prepared based on the required roadway widths, cross slope, and any superelevation requirements. Again, many CADD software packages allow the designer to iteratively evaluate and design various road cross-section configurations and link them to the proposed profile to quickly generate contours along the road alignments that facilitate development of the preliminary site-grading plan.

When preparing a preliminary site plan, similar three-dimensional considerations must be given to the location of parking areas, building placement, vehicular and pedestrian circulation paths, and landscaped areas. The overall development of the site layout plan should take these grading requirements into consideration so that the grading concept is developed as the layout progresses, as opposed to following after the layout is complete. See Figure 19.1.

HYDROLOGIC ANALYSIS

The emphasis on vertical or three-dimensional thinking during preliminary site layout is due in large part to the increasing importance of drainage and stormwater management considerations. Site layout, grading, and drainage are interrelated: stormwater management systems are integral parts of a functional site and require early attention in order to ensure sufficient space is allotted and adequate outfall scenarios assessed. In order to develop a comprehensive stormwater management program—one that meets applicable jurisdictional guidelines and adheres to client/developer expectations and project goals—the engineer must have a thorough understanding of the site hydrologic conditions.

The hydrologic conditions of a site—the topography, soils, land cover condition, and rainfall pattern—are assessed pre- and postdevelopment and compared. This comparison determines the applicable stormwater management requirements and reveals feasible strategies for managing site runoff.

Figure 19.1 Example of a preliminary site plan.

Like all components of the design process, the hydrologic analysis is often iterative, especially when it comes to assessing the postdevelopment scenario. Hydrologic analysis performed as part of the preliminary engineering effort is often updated, checked, and rechecked as the site layout and grading scheme are resolved in increasing detail throughout schematic design and again during final design.

The preliminary engineering hydrologic analysis should be performed at a level of detail sufficient to confirm applicable requirements and ensure that adequate facilities can be provided to meet those requirements. This is particularly important for projects subject to the public review process, as the facilities shown on the preliminary plan and reviewed in the public hearing process by jurisdictional staff and local citizens are those that the client/developer is often committed to deliver. The importance and validity of the preliminary plan is established by ordinance and in some jurisdictions reaffirmed through proffers or development conditions often related to specific infrastructure components such as stormwater management facilities. These proffers and development conditions can be very specific, leaving little wiggle room during the final design process. As such, it is important for the preliminary engineering hydrologic analysis and related design efforts to be accurate but conservative.

The following discussion constitutes a primer on the popular methodologies for hydrologic analysis. It is important to understand that certain sites may warrant more or less detailed investigation, and, at times, alternate methodologies (of which there are many) may be required due to either site conditions or jurisdictional design standards. The engineer should be aware of the jurisdictional requirements prior to initiating the detailed hydrologic study.

Rainfall and Runoff

Every rainfall event is unique. Temporal and spatial precipitation varies seasonally as well as within a storm event due to the prevailing climatic conditions at the time of the storm. Just as every rainfall event is unique, the resulting runoff from a storm event is also unique. The temporal and spatial distribution of the precipitation event affects the temporal and spatial distribution of runoff. Additionally, surface conditions such as the amount of vegetation, land use, soil type and condition, topography, and other factors affect the volume and distribution of runoff. When designing the individual components of a storm drain system, the effects of the temporal and spatial distribution of runoff have little impact. However, these effects must be considered when designing larger components, such as stormwater management facilities and major culverts, or determining the floodplain.

Hydrologic data is historic by nature. Unlike conventional experiments, where data is collected through repetition, hydrologic data is collected through observation of an event (e.g., a measured amount of rainfall for a storm or the floodwater depth). The variables relating to hydrologic data, such as time and space variation of rainfall, abstractions, surface conditions, and numerous others that affect runoff, are considered continuous variables. That is, quantitatively, they can assume any real value. Because the combinations of values of all such variables are infinite, an exact repeat occurrence of an event, although not impossible, is very unlikely.

The infinite number of possible rainfall and runoff events presents an improbable task of ever obtaining all of the unique data potentially available in the hopes of predicting hydrologic events precisely and accurately. Therefore, statistical generalizations are used to represent design storm events, and probability analysis is used to predict the likelihood of occurrence of a random event such as a given design storm.

Exceedence Probability and Recurrence Interval. Generally, hydrologic events are predicted by stating their exceedence probability or recurrence interval. The exceedence probability represents the likelihood that an event of specified magnitude will be exceeded in a given time period. Typically, the time period is one year for most hydrologic events. Similarly, the return period represents the *average* length of time that will pass between events having the same magnitude. For example, a 100-year frequency return period for a rainfall event means that *on the average,* there is a 1 percent chance that this rainfall event will be *exceeded* in any year. A 10-year frequency return period rainfall event would, on average, have a 10 percent chance of being exceeded in any year, and so on. Specifically the recurrence interval is:

$$T_r = \frac{1}{P} \times 100 \tag{19.1}$$

where T_r is the recurrence interval and P is the probability in percent. Hence a 1 percent exceedence probability has a recurrence interval of 100 years.

The concept of exceedence probability and recurrence interval is often misinterpreted. If a 500-cubic-foot-per-second (cfs) discharge has a recurrence interval of 100 years, this does not imply that 500 cfs will occur only once in 100 years. Likewise, if a particular event occurs today, then it will not occur for the next T_r years is not the proper interpretation of the recurrence interval. The recurrence interval represents the statistical average number of years between similar events, given a very long period of record.

Occasionally, it is necessary to determine the probability of a specific event being exceeded within a specific time. The probability P of an event, having a given return period T_r, occurring at least once in N successive years is given as:

$$P = 1 - \left(1 - \frac{1}{T_R}\right)^N \tag{19.2}$$

A distinction exists between the probability of an event occurring at least once and exactly once in a given time period. Another form of the risk equation determines the probability that an event will occur a precise number of times in a given period. In this equation,

$$P = \frac{(N!)\left(\frac{1}{T_r}\right)^I \left(1 - \frac{1}{T_r}\right)^{N-I}}{I!(N-I)!} \tag{19.3}$$

Here, I is the exact number of times the event with T_r occurs in N successive years.

Design Storms

A design storm is the defined result of a statistically estimated rainfall-runoff event used in the design of hydraulic systems. Depending on the hydrologic technique selected, the design storm can be inferred from point precipitation depths (rainfall data), fabricated (synthetic) hydrographs, or isohyetal maps using predetermined spatial storm patterns. It is important to note that the design storm is not an actual storm of record. Rather, it is a fabricated storm compiled from average characteristics of previous storm events, and for convenience and standardization, most review agencies dictate the design storm(s) for use in the design process.

Every storm produces different peak discharges of runoff, has different times to the peak discharge, and consequently different volumes of runoff. Therefore, a specific design storm is characterized by at least two of the following three items:

1. *Duration:* The length of time of the storm event
2. *Depth:* The total amount of precipitation for the duration of the storm event
3. *Frequency:* The average time between two events of similar duration and depth

Additional criteria, used in the hydrologic design process, derived from the foregoing are:

4. *Intensity:* Depth divided by duration
5. *Volume of precipitation:* Depth multiplied by areal coverage of the storm

It is important to recognize that the precipitation volume is not necessarily equal to the runoff volume. Runoff is the amount of *excess* precipitation, that is, the amount of rainfall after all abstractions, including infiltration, evapotranspiration, and depression storage, have been accounted for.

A distinction should also be recognized between intensity and depth-duration relationships. The same depth of rainfall can be produced by different combinations of intensities and durations. Conversely, the same intensity produces different depths of rainfall for various durations. The important concept in design is to specify two of the three parameters (intensity, duration, and frequency) for the design storm to be meaningful.

Table 19.1 provides general guidelines for recurrence interval storms for selected hydraulic systems typical of many local, state, and federal requirements. The duration is specified by the local public agencies.

Intensity-Duration-Frequency Curves

The hydrologic procedure selected to establish the rainfall-runoff relationship determines the type of data required to generate the design storm. Simple types of computational procedures, such as the rational method, require basic intensity-duration-frequency curves, whereas more sophisticated hydrologic approaches require hyetographs (time variation of precipitation) or hydrographs (time variation of runoff) as input. Data specific to the particular model selected is available from various public agencies.

In 1961 the U.S. Weather Bureau published the *Rainfall Frequency Atlas of the United States,* commonly known as Technical Paper No. 40 (TP-40). Since then, the National Oceanic and Atmospheric Administration's National Weather Service (NOAA's NWS) has updated portions of the country's rainfall data by introducing NOAA Atlas 14. NOAA Atlas 14 updated the rainfall data for many mid-Atlantic, Ohio Valley, and southwest states. Current precipitation frequency data can be found at the NWS website (http://hdsc.nws.noaa.gov/hdsc/pfds/index.html). Although rainfall data has been updated by the NWS, not all localities have adopted the change

TABLE 19.1 Guidelines for Design Storms for Various Hydraulic Systems

Hydraulic System	Design Recurrence Interval
Minor storm drain system	2- to 25-year
Major storm drain system	10- to 50-year
Road culverts crossing minor streams	10- to 50-year
Road culverts crossing major streams	25- to 100-year
Small on-site detention/retention ponds	2-, 10-, 25-, 100-year
Large on-site or regional pond	100-year to PMF*
Floodplains on minor streams	10-year to 100-year
Floodplains on major streams	100-year+

*Probable maximum flood.

yet. The engineer should always check with the jurisdiction to determine the applicable rainfall values to use for design purposes.

This document contains rainfall depth maps of the United States for the 1-, 2-, 5-, 10-, 25-, and 100-year recurrence interval storms for durations of 1, 2, 3, 6, 12, and 24 hours for areas east of the 105° meridian. For storm durations of less than 1 hour (and not covered by Atlas 14), the TP-40 information has been superseded by NOAA's Technical Memorandum NWS HYDRO-35. Precipitation data west of the 105° meridian is available through NOAA on a state-by-state basis. Examples of isopluvial maps in these documents are shown in Figures 19.2 through 19.7. (Isohyets depict spatial variation of rainfall—lines that connect points on a map of equal rainfall depth. Isopluvials are isohyets shown on regional rainfall maps.)

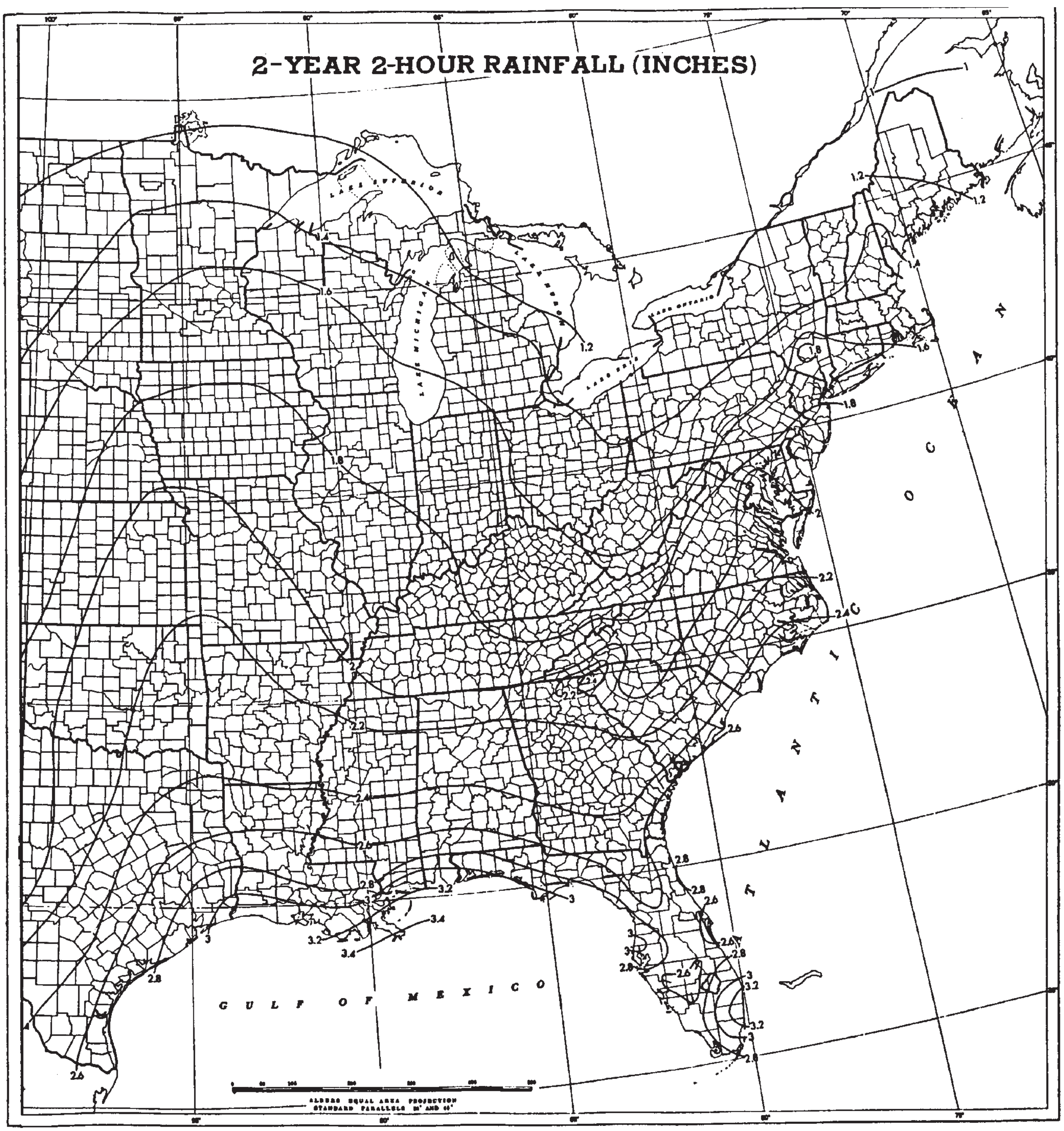


FIGURE 19.2 Isopluvial map.

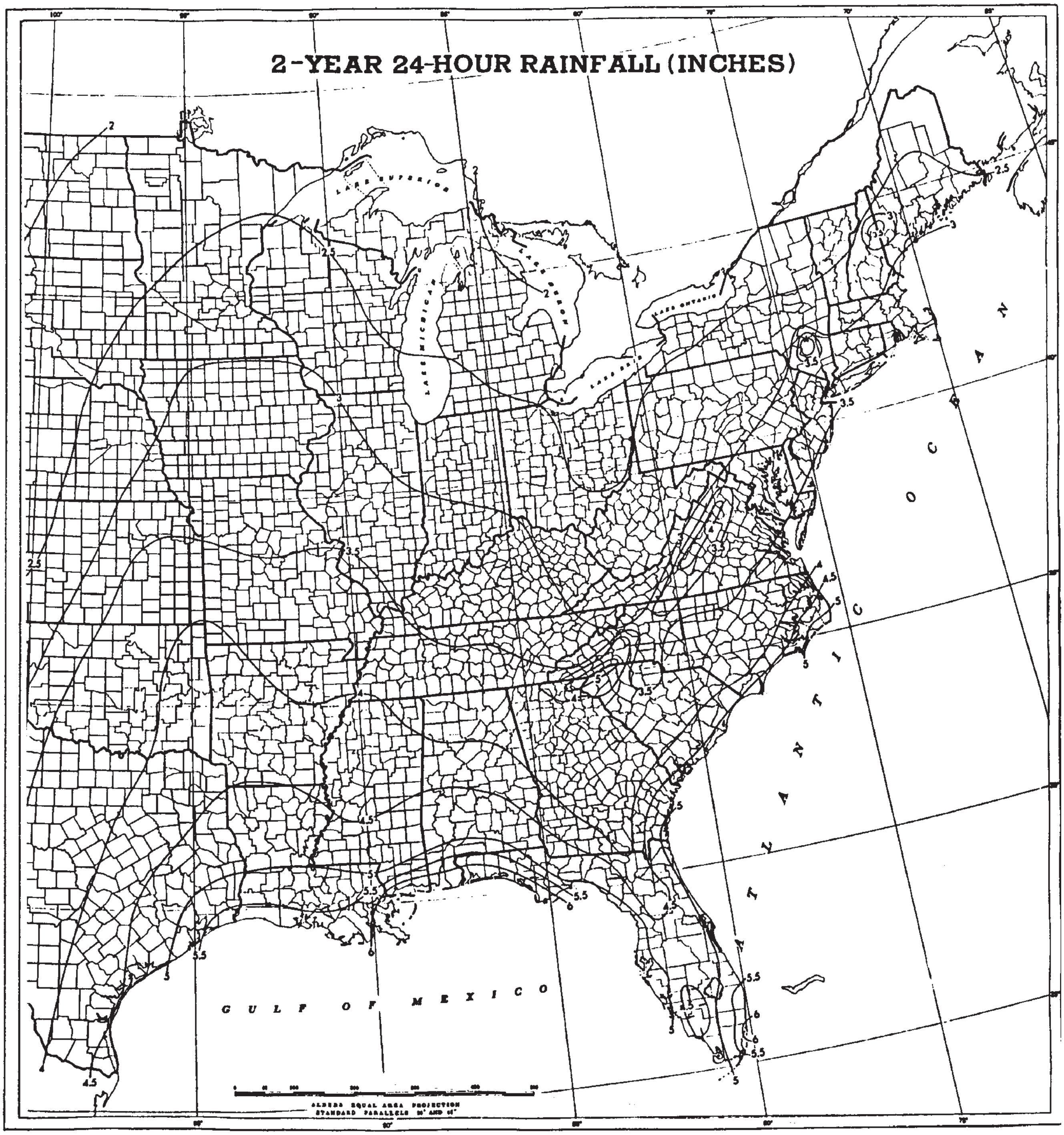


Figure 19.3 Isopluvial map.

Table 19.2 lists the relevant precipitation atlas series or references currently available for use in the United States. Other selected depth-frequency references are listed in Table 19.3.

Point depths, such as those on TP-40, apply to areas less than about 10 square miles. Reductions in point depths are required for large catchments to account for variations of storm depths within catchment areas. A depth-area reduction chart is used to determine the percentage of reduction to be applied to point depths for large catchment areas. However, since most catchments in land development projects are less than 10 square miles, this is of little consequence to the design engineer of most land development projects.

Intensity-duration-frequency (IDF) curves present hydrologic data in another format for use as design storm information. These curves show precipitation intensity on the

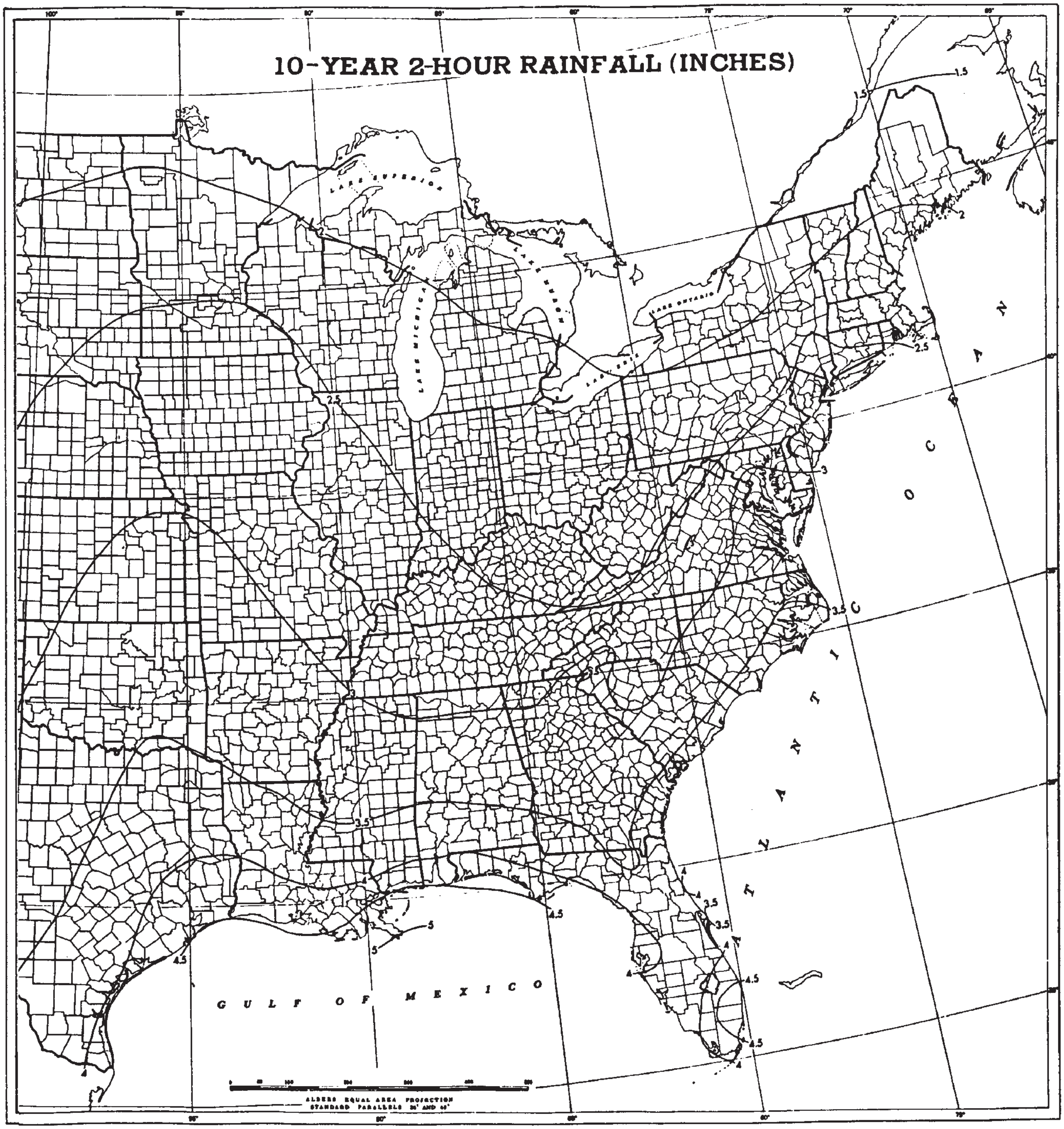


FIGURE 19.4 Isopluvial map.

ordinate (*y* axis), duration along the abscissa (*x* axis), and a series of curves representing individual storm frequencies. The IDF curves are developed through statistical analysis of long-time series rainfall data. They graphically represent the probability that a certain *average* rainfall intensity will occur, given a duration. Note: This is quite different from the misconception that they represent an actual duration or actual time history of rainfall. A single IDF curve represents data from several different storms. The IDF is fabricated from extracting rainfall depths from selected time segments of longer storms. Procedures for constructing IDF curves are discussed in McPherson (1978). These curves are used mainly in conjunction with the rational method for determining peak runoff. See Figure 19.8 for a typical IDF curve.

IDF curves are available through many local agencies such as the state highway departments and the Natural

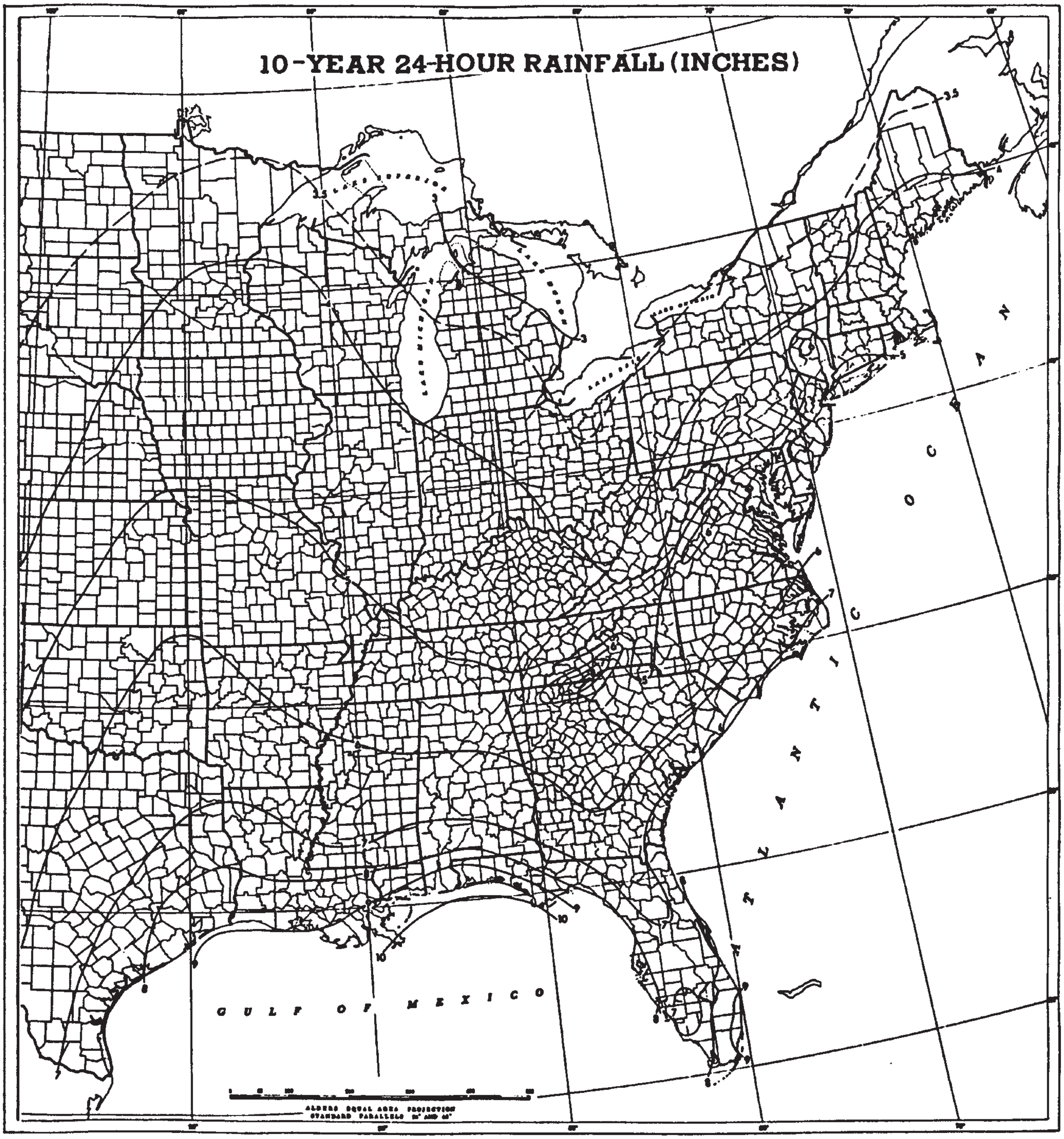


Figure 19.5 Ten-year 24-hour rainfall map.

Resources Conservation Service (NRCS), formerly the Soil Conservation Service (SCS). In rare cases where IDF curves cannot be obtained, they can be developed from current and applicable U.S. Weather Service maps or from frequency analysis using local rainfall information. Discussions on developing IDF curves through frequency analysis are provided in Chow (1959) and Kibler (1982) in the references for this chapter. Besides NOAA Atlas 14, TP-40, and HYDRO-35, the NWS provides other documents relating the depth-duration-frequency of storms, as listed in Table 19.3.

Rational Method Hydrology

For small urban drainage areas, common in minor storm drainage design, it is assumed that short-duration high-intensity storms are the cause of flooding. For such short-duration storms and small drainage areas, the rainfall

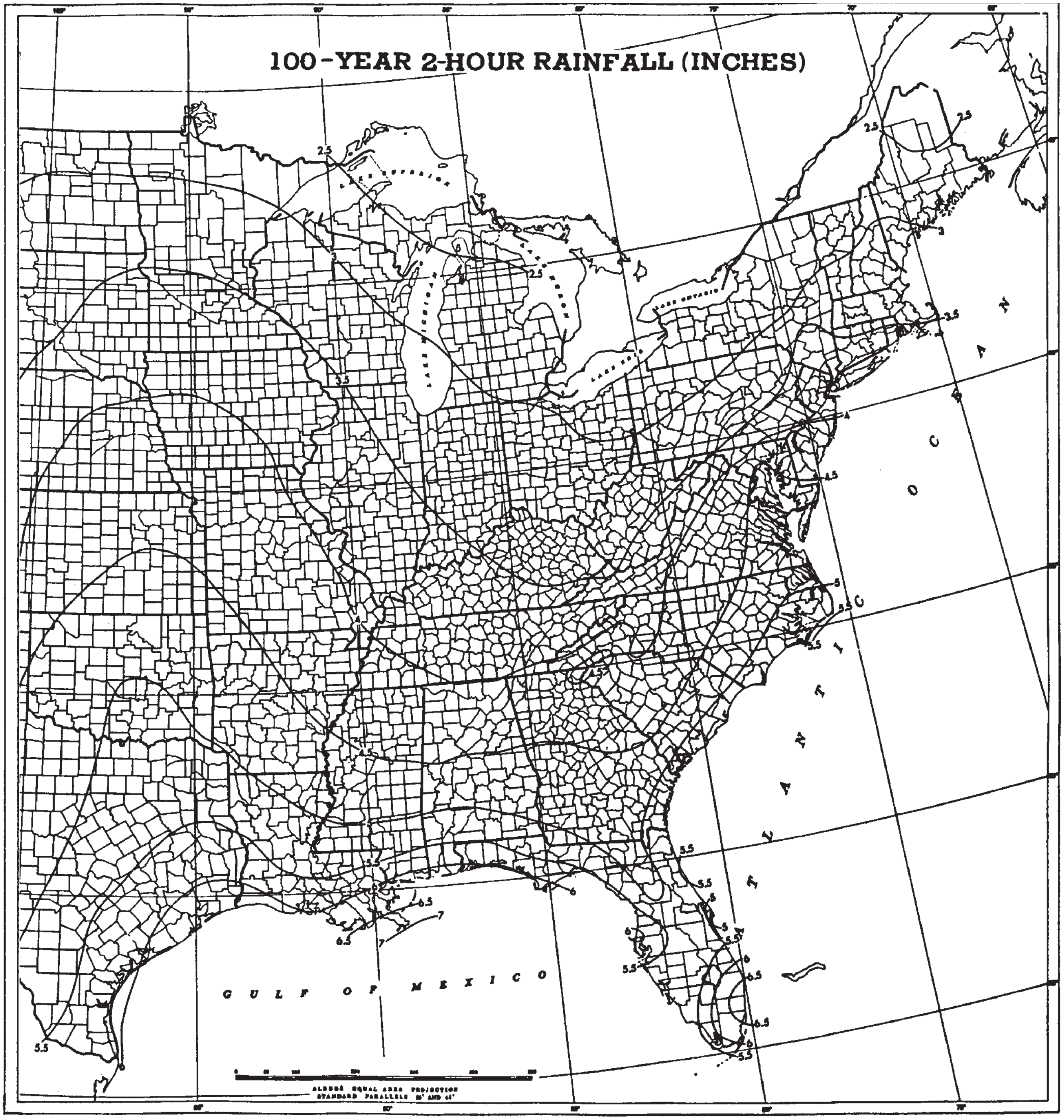


FIGURE 19.6 One-hundred-year 2-hour isopluvial map.

intensity is often assumed constant and the peak runoff rate occurs when the entire drainage area is contributing to the runoff—that is, when the drainage area is in steady-state equilibrium. If a storm of constant intensity begins instantaneously, the rate of runoff for the catchment steadily increases until the entire drainage area is contributing to the discharge at the outlet point. From then on, the drainage area is in equilibrium. All precipitation is converted to runoff, and the peak runoff remains uniform for the duration of the constant-intensity rainfall.

Peak runoff from the rational method is given by:

$$Q_P = CiA \tag{19.4}$$

where Q_p is the peak discharge in cfs, A is the drainage area in acres, C is a runoff coefficient characteristic of the ground surface ($0 < C < 1$), and i is the average rainfall intensity

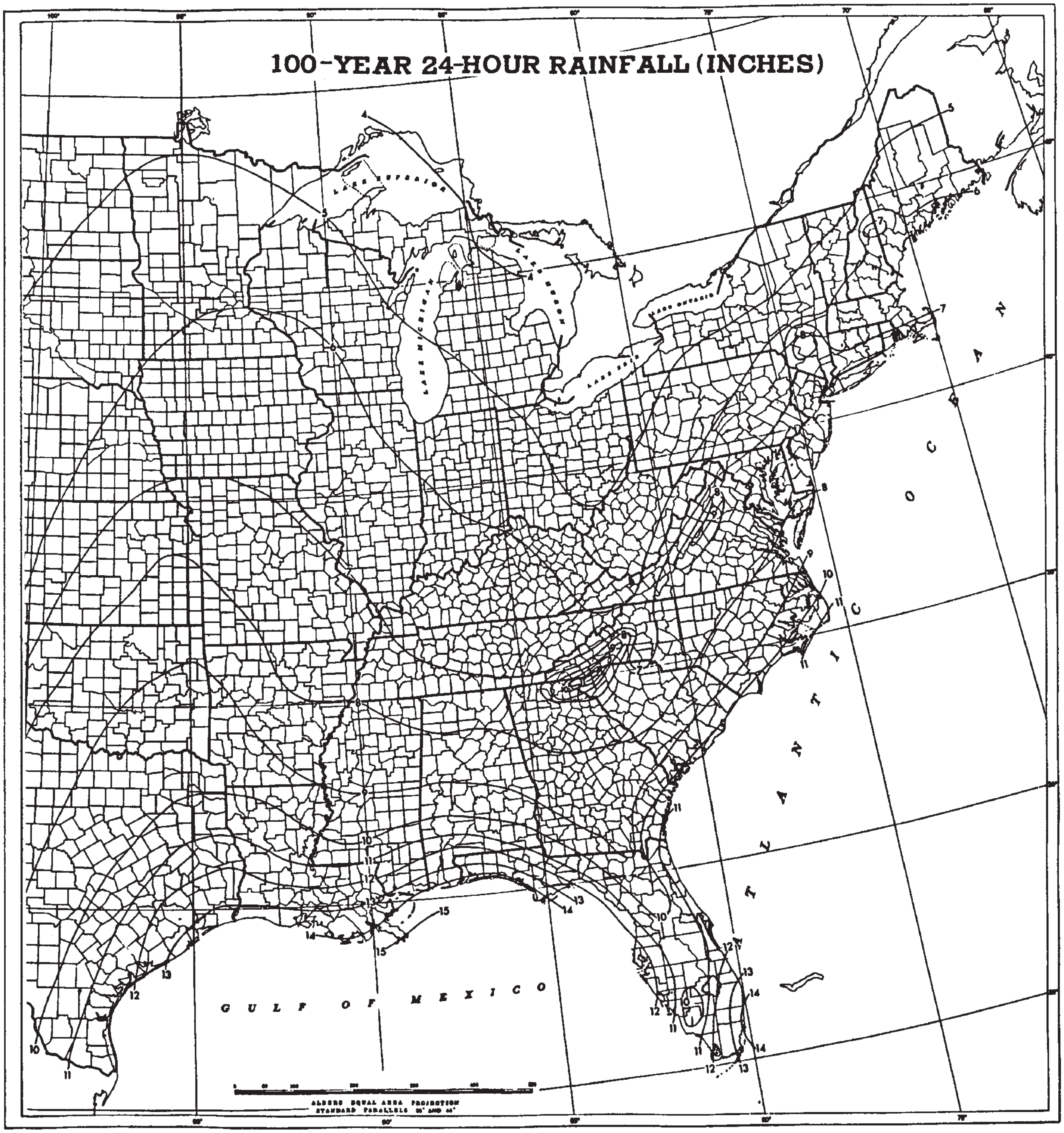


Figure 19.7 Isopluvial map.

(in/hr). The precision of the peak discharge depends on the estimated values of C and i. The average rainfall intensity is a function of the time of concentration of the drainage area.

The rational method is best utilized for small drainage areas. Most localities have maximum restrictions on the applicability of the rational method, ranging from 20 acres to 200 acres. Common practice limits the use of the rational method to areas less than 100 acres. Other jurisdictions also place time-of-concentration restrictions on the use of the rational method, limiting the maximum time of concentration to 60 minutes.

Runoff Coefficient. In Equation 19.4, the product iA can be considered as the inflow to the catchment while also representing the maximum possible runoff rate. The ratio of peak discharge Q_p to inflow iA is the runoff coefficient C. This coefficient can be considered as a lump-sum parameter

TABLE 19.2 Current NWS Precipitation Frequency Publications

LOCATION	5 MIN.–60 MIN.	1 HR.–24 HR.	2 DAY–10 DAY
Arizona, Nevada, New Mexico, Utah, and Southeast California	NOAA Atlas 14 (2003)	NOAA Atlas 14 (2003)	NOAA Atlas 14 (2003)
Remainder of the Western U.S.	Arkell & Richards (1986) Frederick & Miller (1979)	NOAA Atlas 2 (1973)	Tech. Paper 49 (1964)
Delaware, Illinois, Indiana, Kentucky, Maryland, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, West Virginia, and Washington, DC	NOAA Atlas 14, Volume 2 (June 2004)	NOAA Atlas 14, Volume 2 (June 2004)	NOAA Atlas 14, Volume 2 (June 2004)
Remainder of the Eastern U.S.	Tech. Memo 35 (1977)	Tech. Paper 40 (1961)	Tech. Paper 49 (1964)
Hawaii	Tech. Paper 43 (1962)	Tech. Paper 43 (1962)	Tech. Paper 51 (1965)
Alaska	Tech. Paper 47 (1963)	Tech. Paper 47 (1963)	Tech. Paper 52 (1965)
Puerto Rico	NOAA Atlas 14, Volume 3	NOAA Atlas 14, Volume 3	NOAA Atlas 14, Volume 3

that accounts for abstractions (losses before runoff begins, including mainly interception, infiltration, and surface storage), antecedent runoff conditions (index of the runoff potential of the soil before a storm event), and other variables affecting the runoff rate. Table 19.4 identifies the version of the runoff coefficient used by the American Society of Civil Engineers (ASCE), and the standards used in Austin, Texas, are shown as an example in Table 19.5.

Note that the coefficient C is also a function of the recurrence interval of the storm. The reason for this function is an attempt to approximate soil saturation conditions. For larger storm events, it is agreed that the soil has already been saturated to such an extent that it no longer has the infiltration characteristics associated with everyday conditions. Therefore, since the soil is saturated, the rainfall will produce more runoff; the greater the saturation of the soil, the higher the C coefficient and, hence, the greater the runoff.

Other localities account for the change in C coefficient versus recurrence interval by using a correction factor. For example, using the correction factor, Equation 19.4 becomes:

$$Q_P = C_f C i A \tag{19.5}$$

where the correction factor C_f varies by recurrence interval. Comparing the City of Austin example in Table 19.5, the C coefficient would remain the same for all storms; however, the C_f factor would change for storms greater than the two-year event. C_f would equal 1.066, 1.107, 1.178, 1.233, 1.301, and 1.370 for the 5-, 10-, 25-, 50-, 100-, and 500-year events. The engineer should check with the local agency to determine whether correction factors exist.

Use of hydrologic soil groups is more common in NRCS hydrology (discussed later); however, Table 19.6 is useful in that it correlates the C coefficient to hydrologic soil groups and slope ranges with various types of land use.

Whenever a single catchment area consists of several areas with different C coefficients, a weighted coefficient is computed. The weighted coefficient is found by:

$$C_w = \frac{\sum_{i=1}^{m} C_i A_i}{A_T} \tag{19.6}$$

where C_w is the weighted C coefficient, A_i is the area of the subarea with C_i coefficient, and A_T is the total area of the catchment.

Time of Concentration. The time of concentration is the time for water to flow from the most hydraulically remote point of the drainage area to the outlet point. Recognize that this does not imply the most distant point in terms of length. Rather, it is considered as the longest flow time from some point in the drainage area to the outlet point. For example, the point most distant could be drained by storm sewers, which would accelerate the travel time to the outlet point, while an area closer to the outlet point could travel over natural terrain, thus slowing it down. When runoff from the most hydraulically remote point reaches the outlet, the entire catchment area is then contributing to the discharge.

The time of concentration is the sum of two components: (1) the overland flow time (or inlet time) and (2) the channel (or conveyance) time. Overland flow is typically thought of as a flowing thin layer without any significant depth, before it concentrates in defined swales and channels. This could also be referred to as inlet time, since overland flow is basically confined to a short stretch often draining to a catchment, such as a street inlet. Channel time is that part of the flow time

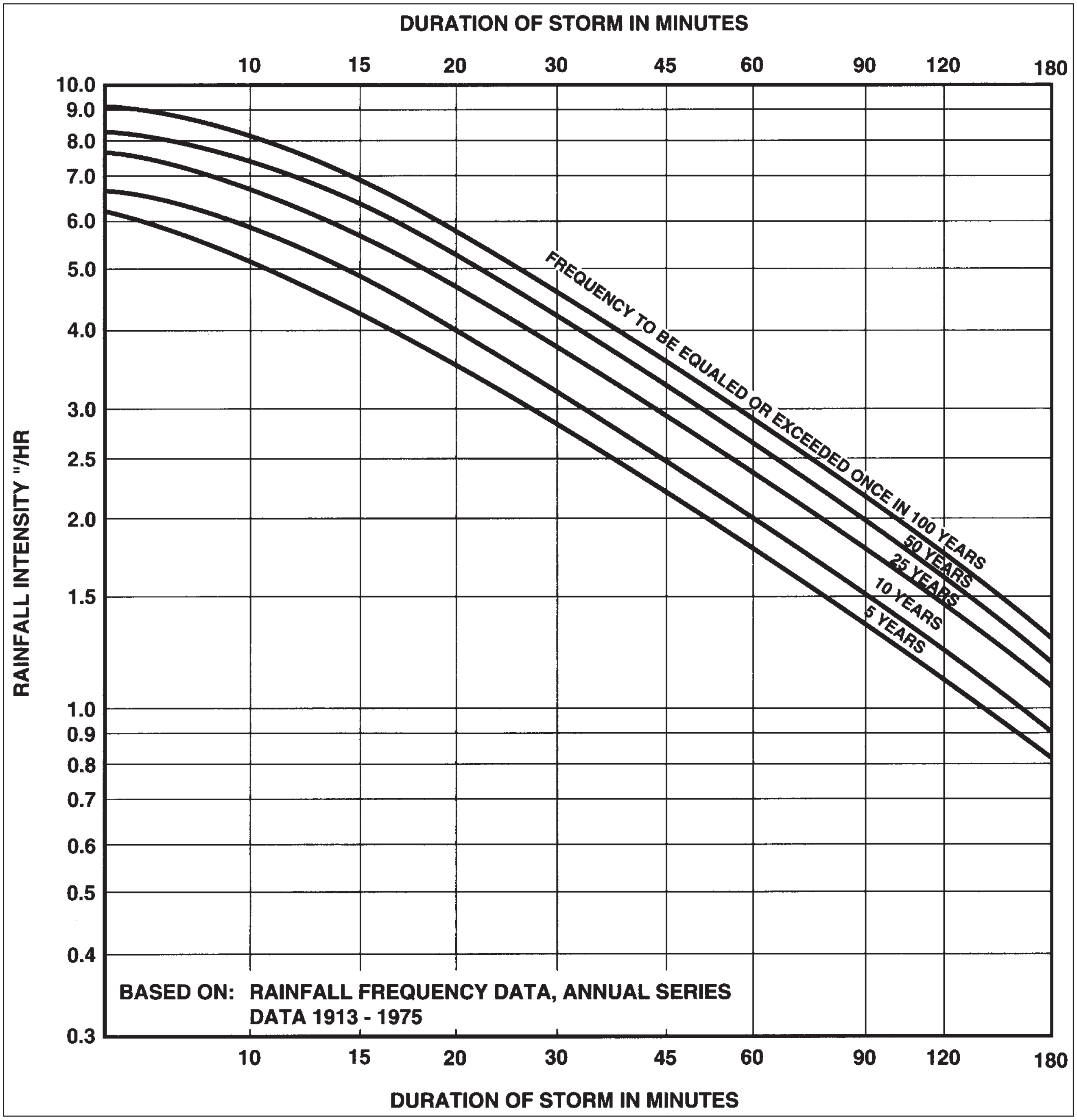


Figure 19.8 Intensity-duration-frequency curves.

when the runoff proceeds as concentrated flow in perhaps irregular but well-defined channels. Often, time is estimated using the average velocity for the hydraulic characteristics of the channel. Although overland flow is occasionally referred to as sheet flow—that is, flow over plane surfaces—it should not, in the context of the rational method, be confused with the NRCS's hydrologic definitions of sheet flow and overland flow (see discussion later in this chapter).

The time of concentration varies according to hydraulic characteristics of the watershed and the storm event itself. Generally, for use in the rational method, the time of concentration is never taken as less than five minutes—even for the smallest catchment and nearly impervious ground surface. The time of concentration varies from 5 to 10 minutes for paved areas with average slopes in the 2 to 10% range and where the flow path to the inlet is 100 to 500 feet. For grassed areas the time of concentration may vary between 5 to 30 minutes for flow paths between 100 and 500+ feet.

There are numerous empirical methods to determine the inlet time of concentration. The method selected depends

TABLE 19.3 NWS Depth-Duration-Frequency References

U.S. Weather Bureau, *Generalized Estimate of Probable Maximum Precipitation and Rainfall Frequency Data for Puerto Rico and Virgin Islands for Areas to 400 Square Miles, Durations to 24 Hours, and Return Periods from 1 to 100 Years,* Technical Paper No. 42, 1962.

U.S. Weather Bureau, *Rainfall Frequency Atlas of Hawaiian Islands for Areas to 200 Square Miles, Durations to 24 Hours, and Return Periods from 1 to 100 Years,* Technical Paper No. 43, 1962.

U.S. Weather Bureau, *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years,* Technical Paper No. 40, 1963, applicable to States east of the 105th Meridian.

U.S. Weather Bureau, *Probable Maximum Precipitation and Rainfall Frequency Data for Alaska for Areas to 400 Square Miles, Durations to 24 Hours and Return Periods from 1 to 100 Years,* Technical Paper No. 47, 1963.

U.S. Weather Bureau, *Two-to-Ten Day Precipitation for Return Periods of 2 to 100 Years in the Contiguous United States,* Technical Paper No. 49, 1964, applicable to the contiguous United States.

NOAA National Weather Service, *Atlas 2: Precipitation Atlas of the Western United States,* 1973, applicable to the 11 western states.

NOAA National Weather Service, *Five- to 60-Minute Precipitation Frequency for the Eastern and Central United States,* Technical Memorandum NWS HYDRO-35, 1977.

on the information available and the preferences dictated by local review agencies. Some of the various methods are listed in Table 19.7. Two of these methods are subsequently discussed.

One of the better-known methods relating the overland flow time to slope and length parameters is the Kirpich equation. Initially, the equation was developed for small agricultural watersheds with drainage areas less than 200 acres. Over time, adjustment factors have been applied to the equation for application to paved surfaces (see Table 19.7). The Kirpich equation is:

$$t_c = 0.0078\left(\frac{L^{0.77}}{S^{0.385}}\right) \tag{19.7}$$

TABLE 19.4 Runoff Coefficients *C* Recurrence Interval ≤ 10 years*

Description of Area	Runoff Coefficients	Character of Surface	Runoff Coefficients
Business		Pavement	
Downtown	0.70–0.95	Asphalt or concrete	0.70–0.95
Neighborhood	0.50–0.70	Brick	0.70–0.85
Residential		Roofs	
Single-family	0.30–0.50	Lawns, sandy soil	
Multiunits, detached	0.40–0.60	Flat, 2%	0.05–0.10
Multiunits, attached	0.60–0.75	Average, 2–7%	0.10–0.15
Residential, suburban	0.25–0.40	Steep, 7% or more	0.15–0.20
Apartment	0.50–0.70	Lawns, heavy soil	
Industrial		Flat, 2%	0.13–0.17
Light	0.50–0.80	Average, 2–7%	0.18–0.22
Heavy	0.60–0.90	Steep, 7% or more	0.25–0.35
Parks, cemeteries	0.10–0.25		
Railroad yard	0.20–0.35		
Unimproved	0.10–0.30		

Source: From "Design and Construction of Sanitary and Storm Sewers," *ASCE Manual of Practice No. 37,* revised by D. Earl Jones, Jr., 1970.

*For 25- to 100-year recurrence intervals, multiply coefficient by 1.1 and 1.25, respectively, and the product cannot exceed 1.0.

TABLE 19.5 Runoff Coefficients for Use in the Rational Method

	RETURN PERIOD (YEARS)						
CHARACTER OF SURFACE	**2**	**5**	**10**	**25**	**50**	**100**	**500**
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
Poor condition (grass cover less than 50% of the area)							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair condition (grass cover on 50% to 75% of the area)							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (grass cover larger than 75% of the area)							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/woodlands							
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

Note: The values in the table are the standards used by the City of Austin, Texas. Used with permission.

where t_c is the time of concentration in minutes, L is the length of the flow path in feet, and S is the average slope of the flow path = ΔElev/L.

Manning's kinematic solution, in the following form, can be used to compute sheet flow travel time.

$$T_t = \frac{(0.93)(NL)^{1/m}}{(i)^{(m-1/m)}\, S^{1/2m}} \tag{19.8}$$

where T_t is the travel time in minutes, n is Manning's roughness coefficient adjusted for overland flow conditions due to an increase in friction for very shallow flows (see Table 19.8), L is the flow length in feet, i is rainfall intensity (inches/hr), and S is the average land slope (ft/ft) of the overland flow path. The exponent m varies from 1.67 to 3.0 depending on whether the overland flow regime is laminar or turbulent. For fully turbulent flow, m is taken as 1.67. Use of this equation is limited to very shallow depths (<0.1 ft) and for L < 300 feet. The solution to this equation is a trial-and-error procedure performed as follows:

1. Assume a value of i.
2. Use Equation 19.8 to find T_t.
3. Find the actual rainfall intensity from an IDF chart for storm duration of computed T_t.
4. Compare the assumed value of i to the one read from the IDF curve. If they are not close, repeat steps 1 through 4.

TABLE 19.6 Runoff Coefficients for the Rational Formula by Hydrologic Soil Group and Slope Range

	A			B			C			D		
LAND USE	**0–2%**	**2–6%**	**6%+**	**0–2%**	**2–6%**	**6%+**	**0–2%**	**2–6%**	**6%+**	**0–2%**	**2–6%**	**6%+**
Cultivated land	0.08* 0.14†	0.13 0.18	0.16 0.22	0.11 0.16	0.15 0.21	0.21 0.28	0.14 0.20	0.19 0.25	0.26 0.34	0.18 0.24	0.23 0.29	0.31 0.41
Pasture	0.12 0.15	0.20 0.25	0.30 0.37	0.18 0.23	0.28 0.34	0.37 0.45	0.24 0.30	0.34 0.42	0.44 0.52	0.30 0.37	0.40 0.50	0.50 0.62
Meadow	0.10 0.14	0.16 0.22	0.25 0.30	0.14 0.20	0.22 0.28	0.30 0.37	0.20 0.26	0.28 0.35	0.36 0.44	0.24 0.30	0.30 0.40	0.40 0.50
Forest	0.05 0.08	0.08 0.11	0.11 0.14	0.08 0.10	0.11 0.14	0.14 0.18	0.10 0.12	0.13 0.16	0.16 0.20	0.12 0.15	0.16 0.20	0.20 0.25
Residential lot Size ⅛ acre	0.25 0.33	0.28 0.37	0.31 0.40	0.27 0.35	0.30 0.39	0.35 0.44	0.30 0.38	0.33 0.42	0.38 0.49	0.33 0.41	0.36 0.45	0.42 0.54
Lot size ¼ acre	0.22 0.30	0.26 0.34	0.29 0.37	0.24 0.33	0.29 0.37	0.33 0.42	0.27 0.36	0.31 0.40	0.36 0.47	0.30 0.38	0.34 0.42	0.40 0.52
Lot size ⅓ acre	0.19 0.28	0.23 0.32	0.26 0.35	0.22 0.30	0.26 0.35	0.30 0.39	0.25 0.33	0.29 0.38	0.34 0.45	0.28 0.36	0.32 0.40	0.39 0.50
Lot size ½ acre	0.16 0.25	0.20 0.29	0.24 0.32	0.19 0.28	0.23 0.32	0.28 0.36	0.22 0.31	0.27 0.35	0.32 0.42	0.26 0.34	0.30 0.38	0.37 0.46
Lot size 1 acre	0.14 0.22	0.19 0.26	0.22 0.29	0.17 0.24	0.21 0.23	0.26 0.34	0.20 0.28	0.25 0.32	0.31 0.40	0.24 0.31	0.29 0.35	0.35 0.46
Industrial	0.67 0.85	0.68 0.85	0.68 0.86	0.68 0.85	0.68 0.86	0.69 0.86	0.68 0.86	0.69 0.86	0.69 0.87	0.69 0.86	0.69 0.86	0.70 0.88
Commercial	0.71 0.88	0.71 0.88	0.72 0.89	0.71 0.89	0.72 0.89	0.72 0.89	0.72 0.89	0.72 0.89	0.72 0.90	0.72 0.89	0.72 0.89	0.72 0.90
Streets	0.70 0.76	0.71 0.77	0.72 0.79	0.71 0.80	0.72 0.82	0.74 0.84	0.72 0.84	0.73 0.85	0.76 0.89	0.73 0.89	0.75 0.91	0.78 0.95
Open space	0.05 0.11	0.10 0.16	0.14 0.20	0.08 0.14	0.13 0.19	0.19 0.26	0.12 0.18	0.17 0.23	0.24 0.32	0.16 0.22	0.21 0.27	0.28 0.39
Parking	0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97	0.85 0.95	0.86 0.96	0.87 0.97

Source: Kibler, D.F., et al., 1982. *Recommended Hydrologic Procedures for Computing Urban Runoff in Pennsylvania*. Commonwealth of Pa. Harrisburg Pa.: Dept. of Environmental Resources.

*Runoff coefficients for storm recurrence intervals less than 25 years.

†Runoff coefficients for storm recurrence intervals of 25 years or more.

Figures 19.9 and 19.10 represent nomographs used to solve the time of concentration equations for the Kirpich method and the Manning's kinematic solution, respectively.

Often, large catchments require the consideration of several flow paths in determining which represents the time of concentration. The flow path with the longest travel time is typically selected for design. However, there are exceptions to this blanket statement. Since the rational method is best suited for homogeneous drainage areas (i.e., consistent land use and topography) that increase linearly with length, both the shape of the drainage basin and its homogeneity affect the peak discharge at various points within the catchment. For those situations where catchment area and length are not linearly related or when the catchment

TABLE 19.7 Summary of Time of Concentration Formulas

METHOD AND DATE	FORMULA FOR t_c (min)	REMARKS
Kirpich (1940)	$t_c = 0.0078L^{0.77}S^{-0.385}$ L = length of channel/ditch from headwater to outlet (ft) S = average watershed slope (ft/ft)	Developed from SCS data for seven rural basins in Tennessee with well-defined channel and steep slopes (3–10%); for overland flow on concrete or asphalt surfaces multiply t_c by 0.4; for concrete channels multiply by 0.2; no adjustments for overland flow on bare soil or flow in roadside ditches.
California Culverts Practice (1942)	$t_c = 60\left(11.9\,\frac{L^3}{H}\right)^{0.385}$ L = length of longest watercourse (mi) H = elevation difference between divide and outlet (ft)	Essentially the Kirpich formula; developed from small mountainous basins in California (U.S. Bureau of Reclamation, pp. 67–71, 1973).
Izzard (1946)	$t_c = \frac{41.025(0.007\,i + c)L^{0.33}}{S^{0.33}i^{0.67}}$ i = rainfall intensity (in/hr) c = retardance coefficient L = length of flow path (ft) S = slope of flow path (ft/ft)	Developed in laboratory experiments by Bureau of Public Roads for overland flow on roadway and turf surfaces; values of the retardance coefficient range from 0.0070 for very smooth pavement to 0.012 for concrete pavement to 0.06 for dense turf; solution requires iteration; product i times L should be ≤500.
Federal Aviation Administration (1970)	$t_c = 1.8(1.1 - C)\,\frac{L^{0.5}}{S^{0.33}}$ C = rational method runoff coefficient L = length of overland flow (ft) S = surface slope (%)	Developed from airfield drainage data assembled by the Corps of Engineers; method is intended for use on airfield drainage problems, but has been used frequently for overland flow in urban basins.
Kinematic wave formulas Morgali and Linsley (1965) Aron and Erborge (1973)	$t_c = \frac{0.94\,L^{0.6}n^{0.6}}{i^{0.4}S^{0.3}}$ L = length of overland flow (ft) n = Manning roughness coefficient i = rainfall intensity (in/hr) S = average overland slope (ft/ft)	Overland flow equation developed from kinematic wave analysis surface runoff from developed surfaces; method requires iteration since both i (rainfall intensity) and t_c are unknown; superposition of intensity-duration-frequency curve gives direct graphical solution to t_c.
SCS average velocity charts (1975, 1986)	$t_c = \frac{1}{60} \leq \frac{L}{V}$ L = length of flow path (ft) V = average velocity in feet per second from Figure 3.1 of TR 55 for various surfaces	Overland flow charts in Figure 3-1 of TR 55 show average velocity as function of watercourse slope and surface cover (see also Table 5.7.1).

Source: Kibler, David F., ed. *Urban Stormwater Hydrology Monograph 7*. Copyright 1982 by the American Geophysical Union, Washington, DC.

has widely varied land use, selecting the flow path with the longest t_c does not always produce the peak discharge at the specified location. The following are cases to illustrate this.

The following example shows when the t_c should be carefully considered for nonhomogeneous catchments. Consider the situation given in Figure 19.11 and determine the peak discharge at the outlet, using the rational method.

The rainfall intensity is given as:

$$i = \frac{97.5}{T_d^{0.83} + 6.88} \qquad (19.9)$$

TABLE 19.8 Effective Roughness *N* for Overland Flow*

SURFACE	*N* VALUE
Dense growth	0.40–0.50
Pasture	0.30–0.40
Lawns	0.20–0.30
Bluegrass sod	0.20–0.50
Short prairie grass	0.10–0.20
Sparse vegetation	0.05–0.13
Bare clay-loam soil (eroded)	0.01–0.03
Concrete-asphalt very shallow depths <6 mm	0.10–0.15

*Hydrologic Engineering Center, U.S. Army Corps of Engineers. 1990. *HEC-1 Flood Hydrograph Package Users Manual.*

where T_d is the intensity duration (in minutes). The t_c for the entire watershed is 65 minutes. Assuming $T_d = t_c$, the rainfall intensity is 2.51 in/hr. The weighted C coefficient for the catchment is:

$$C_w = \frac{(0.2)(60) + (0.7)(30)}{90} = 0.37 \tag{19.10}$$

The peak discharge per the rational method is 83.6 cfs. Compare this to the peak discharge only from the developed area of 108.4 cfs:

$$\begin{aligned} Q_p &= (30\text{ ac})(0.7)(5.16\text{ in/hr}) \\ &= 108.4\text{ cfs } (i = 5.16\text{ in/hr for } t_c = 20\text{ min}) \end{aligned} \tag{19.11}$$

The peak discharge for the entire catchment is less than the peak discharge from the developed areas. This shows the necessity for carefully analyzing the situation when the catchment is nonhomogeneous.

Another example illustrating the need to interpret the t_c is the occasion of composite catchments. Consider the situation where the discharge point drains two widely varied catchments, as in Figure 19.12. For this discussion, the rainfall intensity is given by Equation 19.8. Using the rational method and the longest t_c (60 minutes), a misleading peak discharge at point P is calculated. The weighted C coefficient is:

$$C_N = \frac{(0.7)(30) + (0.3)(80)}{(30 + 80)} = 0.41 \tag{19.12}$$

The peak discharge is:

$$Q_p = (110\text{ ac})(0.41)(2.65\text{ in/hr}) = 119.5\text{ cfs} \tag{19.13}$$

However, the actual peak discharge occurs earlier, when the combined effects of all catchment B and some part of catchment A are contributing. Without sufficient data on catchment A, an assumption must be made on the t_c – area relationship of the catchment. This would require a trial-and-error approach, to incrementally add portions of the drainage area of catchment A, to determine the impacts of peak discharge to point P. Since the rational method is mathematically linear, the trial-and-error process is simplified, and the user should be able to identify the portion of catchment A that increases discharge to point P with only a few iterations. The equation for Q_p for the combined effects is:

$$Q_p = i\left[(C\,A)_B + \left(\frac{(t_c)_{\text{inc}}}{t_c}(C\,A)\right)_A\right] \tag{19.14}$$

where the $(t_c)_{\text{inc}}$ corresponds to an incremental time of concentration greater than 20 minutes and less than 60 minutes and i is the corresponding rainfall intensity. The incremental t_c producing the largest peak discharge is the design discharge. In this case, the largest discharge occurs for a rainfall duration of 20 minutes, as shown in Table 19.9.

Rational Method Summary. The rational method provides adequate results for computing peak discharges as long as it is used properly, with an understanding of the underlying assumptions and limitations. Even with proper understanding of the rational method, as the catchment increases in size, the results become suspect due to the assumption of a steady uniform rain over the entire catchment. Additionally, the inherent uncertainties in the C coefficient are magnified as the catchment area increases. There is disagreement within the engineering community on the upper limit of the catchment size that can effectively utilize the rational method. Values of 200 acres to 1 square mile (640 acres) have been proposed. Certainly for the relatively small catchments (<20 acres) encountered in minor storm drain design, the rational method should be satisfactory for use.

The key element in using the rational method is proper determination of the time of concentration. Due to the hyperbolic shape of the IDF curves, a small error in t_c (i.e., rainfall duration) causes large discrepancies in the intensity. If the estimated t_c is less than the actual t_c, the rainfall intensity will be too high, resulting in a high Q_p. Another important consideration when performing the hydrologic analysis is the dynamics of the land use in the catchment. For projects within a catchment undergoing development, the runoff coefficient should represent the catchment as it might ultimately appear, rather than reflecting current conditions.

To summarize, the basic assumptions in the rational method are:

- Rainfall intensity is uniform and constant over the catchment, and the duration of this rainfall intensity is at least as long as the time of concentration of the catchment.

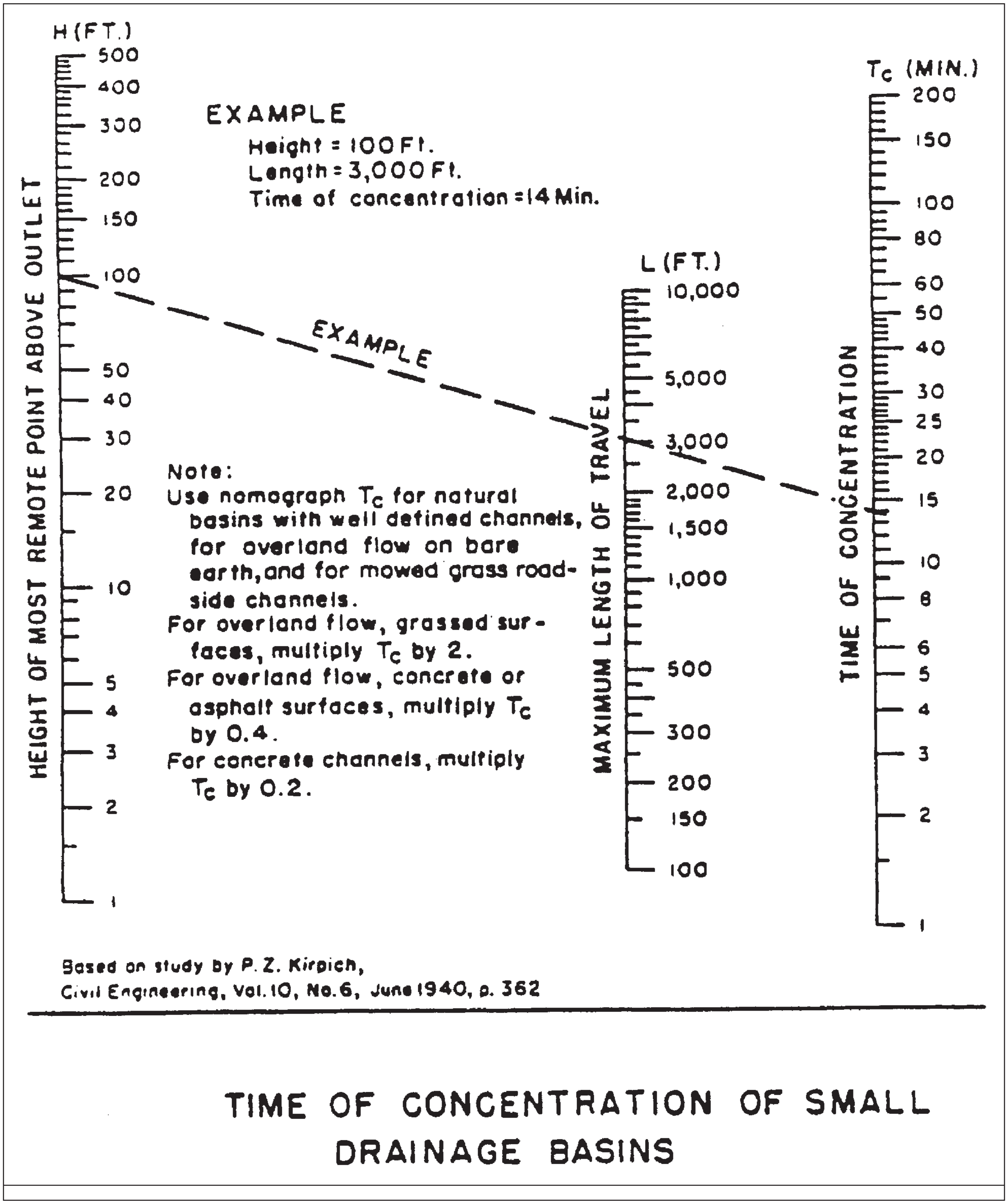


FIGURE 19.9 Time of concentration of small drainage basins (Kirpich method).

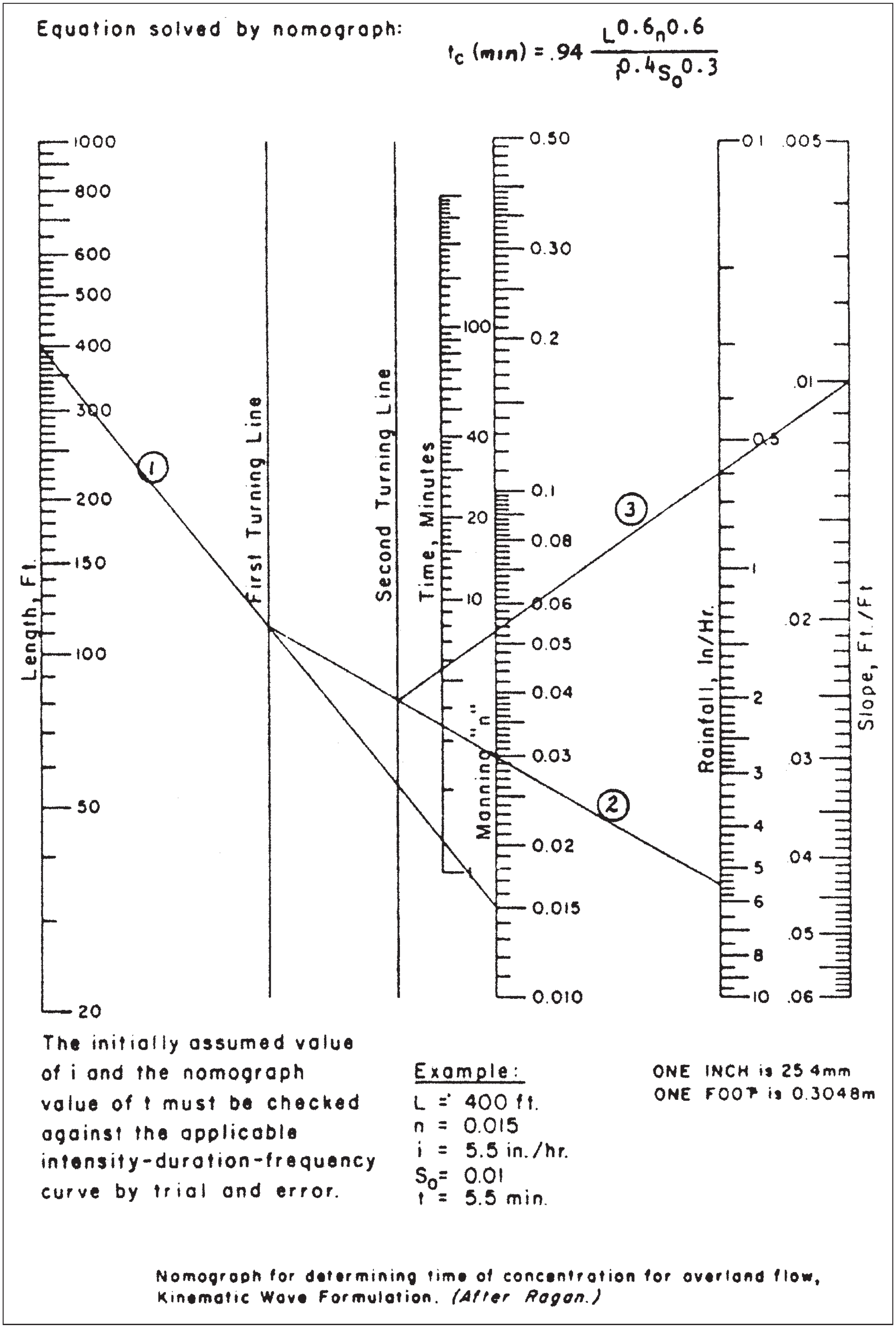


FIGURE 19.10 Time of concentration for overland flow, Manning's kinematic wave formulation.

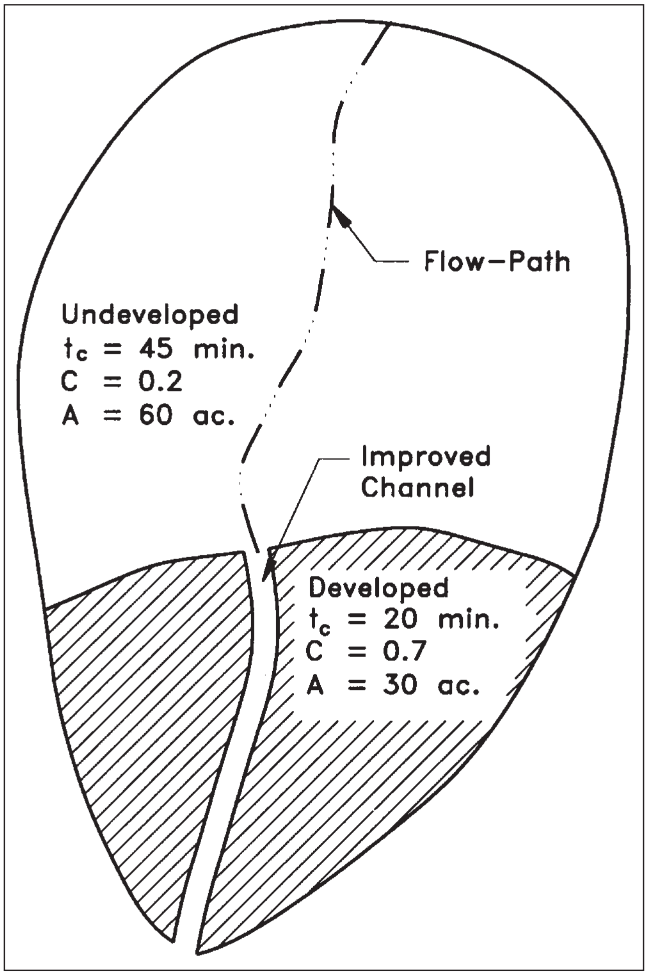


FIGURE 19.11 Catchment with development at the lower end.

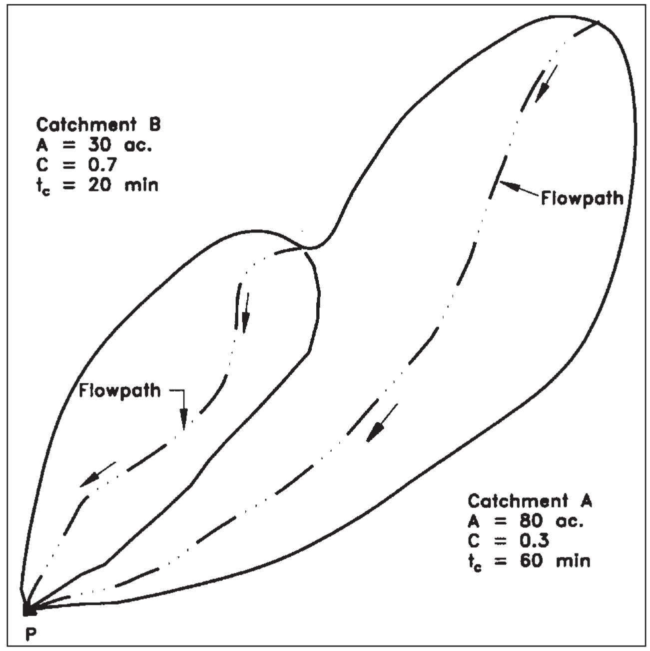


FIGURE 19.12 Composite catchments. (Ponce, Miguel Victor, 1989, *Engineering Hydrology: Principles and Practices,* pp. 128, 129, 138. Adopted by permission of Pearson.)

- The maximum rate of runoff occurs when constant rainfall intensity falls on a catchment for as long as, or longer than, the time of concentration.

- The runoff coefficient is the same for each rainfall intensity and for all return intervals. This is an assumption inherent in the original proposal by Kuichling in 1877. Runoff coefficients are typically higher for the less frequent storms because of the reduction effect of the rainfall abstractions. Runoff coefficients are also increased for the higher-intensity rainfalls for the same reason.

- The frequency of the peak discharge is the same as that of the rainfall intensity for the given time of concentration. This may not necessarily be true due to variations in surface conditions.

- Most localities restrict the use of the rational method to small drainage basins, ranging from 20 to 200 acres, and may limit the applicability of the rational method to catchments with time of concentrations greater than 60 minutes.

Design Example for the Rational Method. Using the rational equation to size pipes and inlets in a storm drain network involves a systematic method of determining a time of concentration to the design point, finding the corresponding rainfall intensity, and applying the rational equation. For each new design point a new t_c and intensity are computed to determine the corresponding peak discharge.

An example illustrates the procedure. Consider the schematic layout in Figure 19.13. The requirement is to determine the discharge at point *e* using the rational method for a 10-year-recurrence-interval storm. A storm drainage network is dendritic in shape—that is, the branches of the pipe network converge in the downstream direction. As such, the discharge increases and the pipes become larger in the downstream direction. Therefore, the design begins at the most upstream catchment for a particular branch of the pipe network. The design discharge for a pipe, using the rational method, is found by determining the longest time of concentration to the inlet of the pipe at the most upstream catchment. Recall that the time of concentration is a combination of overland flow time (i.e., inlet time) plus channel time, where the time of concentration is, typically, the longest accumulated time of overland flow plus channel time.[1] To compute the channel time in a stream, the velocity is computed from Manning's equation using bank-full conditions.

The computations are facilitated with the aid of the pipe design table (Table 19.10). This example is to illustrate the application of the rational method; hence, the pipe design

[1]Some exceptions to this generalized rule have previously been discussed.

TABLE 19.9 Peak Discharge for Incremental Intensity Duration

INTENSITY DURATION (min)	RAINFALL INTENSITY (in/hr)	CONTRIBUTING AREA OF B (ac)	Q_p (cfs)
20	5.16	26.7	149.7
30	4.11	40.0	135.6
40	3.10	53.3	114.6
50	2.99	66.7	122.6
60	2.65	80	119.3

part is ignored. The velocity for flow through the pipes is assumed to be 2.5 fps. In actual practice the flow time is based on the actual discharge, pipe size, and pipe slope. The design discharge for pipe a-c is based on the inlet time of 5 minutes. The area of the catchment is determined by drawing the drainage divides and planimetering or otherwise measuring the area.[2] The runoff coefficient is determined from the land use, topography, and other contributing factors. From the IDF curve, shown in Figure 19.8, the rainfall intensity is 6.5 in/hr and the corresponding peak discharge (from Equation 19.4) to the upper end of pipe a-c is given in column 9 as 10.4 cfs. Similar analysis was applied to pipe b-c to find $Q_p = 5.9$ cfs.

Consider pipe c-d. The discharge to design point c must account for the accumulated *CA* value of all contributing catchments draining to point c, as shown in column 6 (1.6 + 1.0 = 2.6). There are two flow paths that must be considered to determine the t_c: the overland flow from catchment I, column 7 (=5 min), plus time in pipe from a to c, column 15 (=2 min); or the overland flow from catchment II (=10 min) plus time in pipe from catchment II to point c (=0.7 min). The larger t_c is 10.7 minutes. This time is used to determine the intensity *i*, column 8. The peak discharge to point c is:

$$Q_p = i \sum (CA) = (5.8)\, 2.6 = 15.1 \text{ cfs} \qquad (19.15)$$

Point d is a surface inlet structure. The CA value used in calculating the peak discharge at point d is the accumulated CA (=2.6) from all upstream catchments contributing to point d plus the CA (=1.65) that contributes the surface runoff from catchment III. The time of concentration is the longest flow path to point d, the flow path already shown to be b-c plus the time of flow in pipe from point c to d (=2.7 min). The total time of 13.4 minutes is used to determine the intensity of 5.3 in/hr. The corresponding peak discharge is 21.8 cfs flowing through pipe d-e. Note that the t_c used for pipe section d-e was the accumulated time from catchment II to point d. Point d is a surface inlet with a t_c of 10 minutes. If this t_c had been greater than the accumulated time from catchment II, the intensity would have been selected using the t_c from catchment III instead.

Note in the foregoing example problem that the flows at each design point are obtained by successive applications of the rational equation. The time of concentration accumulates as the design progresses downstream. Accordingly, new rainfall intensities are determined at each design point. One typical misuse of the rational method is to calculate flows for each individual catchment and add them at each successive design point. This procedure results in an overestimate of the design flow that accrues in the downstream sections.

NRCS Methodology for Computing Runoff

For relatively small catchments (<200 acres) the rational method can be used to determine peak runoff discharge. However, for larger catchments, designers prefer to use more sophisticated rainfall-runoff models. Although a more sophisticated model does not necessarily provide greater accuracy and better results, there is greater flexibility for calibrating the model to local observations. One such hydrologic model, developed by the Natural Resources Conservation Service

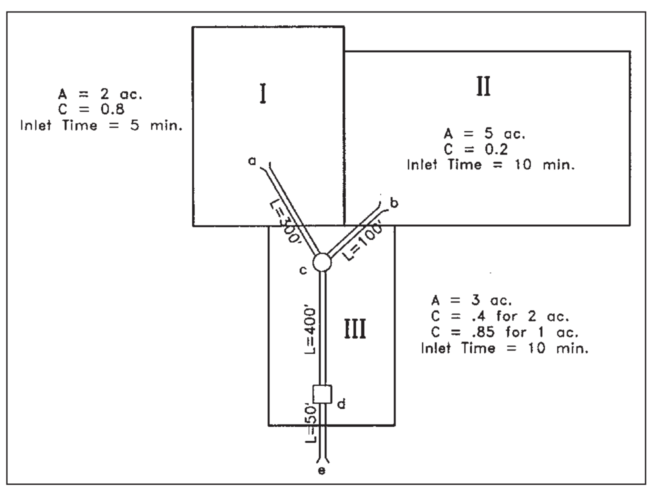


FIGURE 19.13 Schematic for application of the rational method.

[2]A drainage divide shows the area contributing runoff to a particular point. In the simplest case, a drainage divide is determined by starting at the inlet location or other point of interest and tracing a line that is perpendicular to the contour lines. Eventually the line will loop back to the point of origin. However, curbs, drainage ditches, and other conveyance structures may alter the direction of the drainage divide.

TABLE 19.10 Pipe Design Table for Rational Method Design Example

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
From	To	Incr. Area ac	C	$A \times C$	Accum. (ac)	t_c (min) to Upper End (or to inlet)	Rainfall Intensity (in/hr)	Q_p (cfs)	Diameter (in)	L (ft)	Slope	Vel (fps)	Q_{max} (cfs)	Time in Pipe (min)	Accum. Time (min)	Inv. Up	Inv. Low
a	c	2	0.8	1.6	1.6	5	6.5	10.4		300		2.5		2.0	7.0		
b	c	5	0.2	1.0	1.0	10	5.9	5.9		100		2.5		0.7	10.7		
c	d	—	—	—	2.6	10.7	5.8	15.1		400		2.5		2.7	13.4		
d	e	3	.55	1.65	4.3	13.4	5.3	22.8		50		2.5		0.3	13.7		

Column

1,2 Defines the pipe section. Column 1 is the upper end and column 2 the lower end of the pipe.
3 The incremental area contributing to runoff to the pipe section; this column has an entry only if there is an inlet at upper end of pipe.
4 The runoff coefficient for the incremental area (column 3).
5 Column 3 multiplied by column 4.
6 Accumulated (area $\times$ runoff coefficient) draining to the pipe section at the upper end (column 1).
7 Time of concentration to the upper end of the pipe section.
8 Rainfall intensity based on t_c of column 7.
9 Peak discharge to upper end of pipe section equal to column 6 $\times$ column 8.
10 Pipe diameter of pipe section defined by columns 1 and 2.
11 Length of pipe
12 $\text{Slope} = \dfrac{\text{Upper Inv. Elev} - \text{Lower Inv. Elev}}{L}$
13 Velocity of discharge in pipe = Q_p/area of flow.
14 Maximum flow capacity of pipe.
15 Flow time in pipe = Vel/Length.
16 Accumulated time to lower end on pipe section equal to column 7 + column 15.
17 Upper invert elevation of pipe.
18 Lower invert elevation of pipe.

(NRCS), is widely accepted, well documented, and available for use on the computer. Underlying fundamentals of this method are found in the *National Engineering Handbook,* Chapter 4, "Hydrology" (NEH-4), and the computer program documented in Technical Release 20 (TR-20). Recent documentation of NRCS methods is found in Technical Release 55 (TR-55), Urban Hydrology for Small Watersheds, and the new TR-55 Win program. These documents are available from the Government Printing Office, Washington, D.C. Because the NRCS method is routinely used for stormwater management design, a brief discussion of the primary components and principles is provided in the following sections.

For the design of larger stormwater management (SWM) facilities where downstream safety is a major concern in the event of dam failure, local agencies usually require a hydrologic analysis of large storm events such as the probable maximum precipitation (PMP), the probable maximum flood (PMF), or a percentage of the PMF. The PMF is the flood discharge that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The PMP is, theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given-size storm area at a particular geographic location at a certain time of the year.

Rainfall. The NRCS has developed four synthetic rainfall distributions that are indicative of the rainfall intensities inherent to geographic regions of the United States. These four standard rainfall distributions, labeled Type I, Type Ia, Type II, and Type III, have been developed from numerous publications. Since most rainfall data is reported on a 24-hour basis, the NRCS used 24 hours as the duration for these distributions. The location of the peak rainfall intensity (early, center, or late peaking) in each storm is intended to mimic the location of the peak intensity for the particular region of the United States. For example, peak intensities for Type I and Ia storms occur around 8 hours, similar to the storms in the far western part of the United States. Type II and III storms have peak intensities occurring around the midpoint of the duration. Specific geographical areas are shown in Figure 19.14.

Runoff Volume Using Runoff Curve Numbers. The fundamental equation in the NRCS hydrologic method for computing the volume of runoff from a catchment area is:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{19.16}$$

where Q is the runoff in inches over the entire watershed, P is rainfall (in), S is the potential maximum retention (i.e., rain not converted to runoff) after runoff begins (in), and I_a is the initial abstraction (i.e., losses before runoff begins).

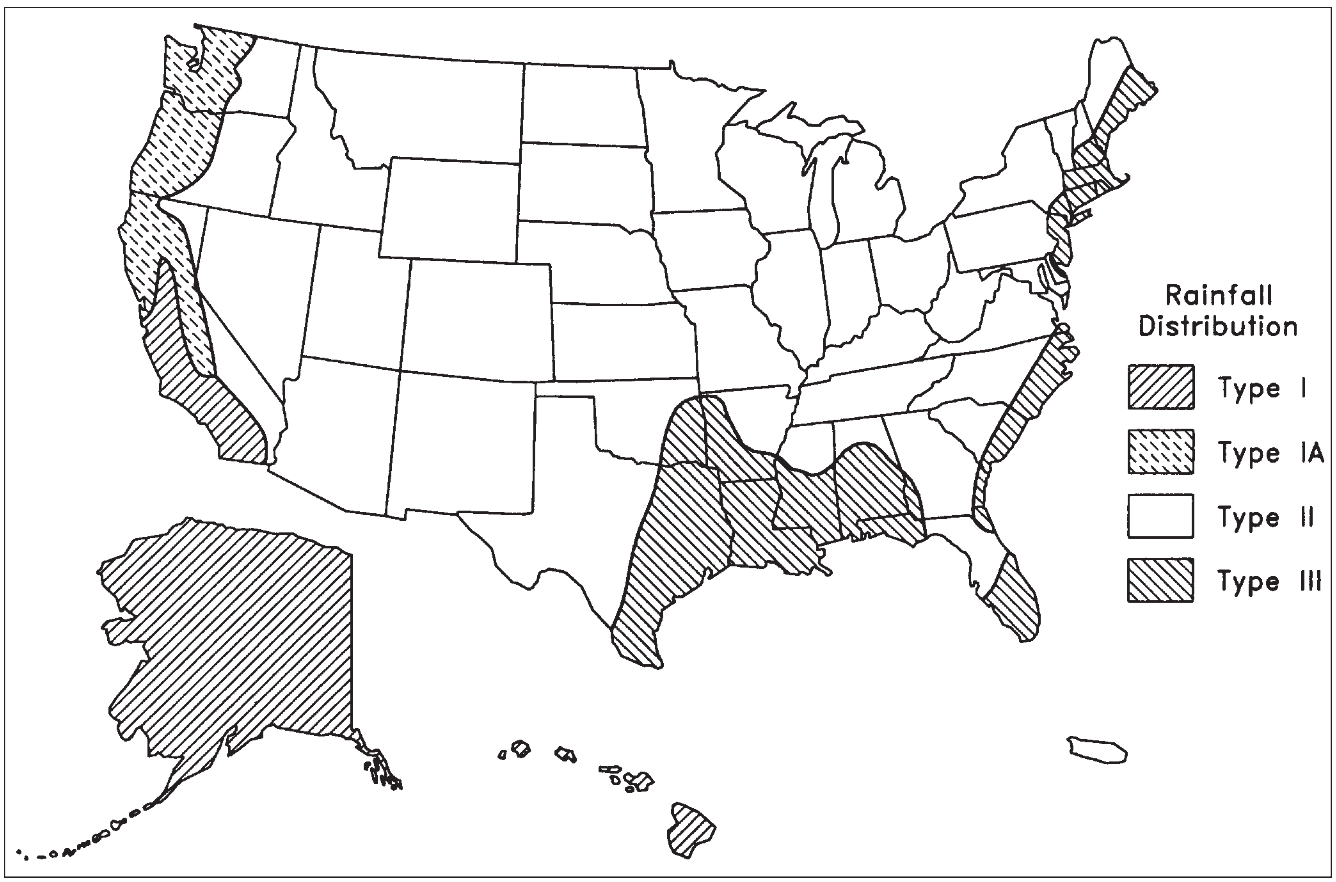


FIGURE 19.14 Approximate geographic boundaries for NRCS rainfall distributions. (*Source:* USDA, TR-55)

Values for I_a depend on characteristics of the soil, land use, and vegetation. Empirically, I_a is taken as equal to 0.2*S*, where *S* is given as:

$$S = \frac{1000}{\text{CN}} - 10 \tag{19.17}$$

and CN is the curve number that relates the runoff to land characteristics. The curve number is analogous to the runoff coefficient used in the rational method. It converts the mass rainfall to runoff and is based on such factors as the hydrologic soil group (HSG), cover type, hydrologic conditions, and antecedent moisture conditions. Using these relationships, the runoff can be expressed in terms of *S:*

$$Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \tag{19.18}$$

In part, the *CN* for a particular soil depends on the HSG classification. Soils are divided into four hydrologic soil groups, A, B, C, and D, according to their minimum infiltration rate. Soils classified in hydrologic group A generally have high infiltration rates (sand), whereas the HSG D has the lowest infiltration rates (clay). The cover type describes the surface of the catchment, such as type and denseness of vegetation and impervious or semi-impervious pavements. It is determined from field reconnaissance, aerial photographs, specialized photography (infrared, etc.), and land use maps. Hydrologic condition (poor, fair, or good) is a measure of the effects of the cover type on infiltration and runoff.

Table 19.11 presents CN values for several types of soils and cover types. It should be noted that these CN values are based on an average antecedent runoff condition. The NRCS publishes soil surveys for the majority of localities in the United States and contains soil classification information. The surveys are found in many different formats including databases and GIS layers. The NRCS is constantly updating information available electronically; refer to http://soils.usda.gov/ for the latest information.

Once the hydrologic soil group and the cover type and antecedent runoff condition have been determined, a weighted CN can be found by determining the areal coverage of each set of conditions and consulting an NRCS curve number table. Figure 19.15 shows the HSG groups overlain on a land use map. A soils map is used to identify the soil series, which is then converted to a hydrologic soil group. This map was created by tracing the HSG map onto the land use map. The worksheet shown in Figure 19.16 is used to tabulate the data and determine the composite CN.

Time of Concentration. The NRCS method for determining t_c consists of computing the travel times associated with runoff over three distinct types of flowpaths, as described here.

1. Sheet flow is the initial phase of runoff characterized as flow over plane surfaces. The flow depth is very shallow (<0.1 ft); consequently, the Manning's roughness coefficient is modified to reflect the increased effects of drag from surface irregularities. Sheet flow is assumed to occur for distances less than 300 ft. The NRCS has issued recent guidance suggesting that 100 ft is the likely maximum distance for sheet flow calculations. The travel time is given as:

$$T_t = \frac{0.007\,(nL)^{0.8}}{(P_2)^{0.5}\,S^{0.4}} \tag{19.19}$$

which is the kinematic solution to Manning's equation. In Equation 19.19, T_t represents the travel time in hours, *n* is the effective Manning's *n* as given in Table 19.12, *L* is the flow length in feet (<300 ft), P_2 is the 2-year/24-hour rainfall (in) given in Figure 19.3, and *s* is the slope of the hydraulic grade line, which is assumed to be the same as the average land slope (ft/ft). See Table 19.12.

2. Shallow concentrated flow occurs after sheet flow. The travel time for shallow concentrated flow is:

$$T = \frac{L}{3600\,V} \tag{19.20}$$

where $V = 16.1345\,(s)^{0.5}$ for unpaved surfaces
$20.3282\,(s)^{0.5}$ for paved surfaces

where *V* is the average runoff velocity (fps), *L* is the flow length (ft), and the travel time *T* is in hours.

3. Eventually runoff collects into defined open channels, which, according to NRCS, are visible on aerial photographs, appear as blue lines on USGS quadrangle sheets, and dissipate where surveyed cross-section information begins, or based on field verification. Travel time in open channels is determined from the average velocity at bank-full flow. Manning's equation for open channel velocity is:

$$V = \frac{1.49}{n}\,R^{2/3}\,S^{1/2} \tag{19.21}$$

where *V* is the average velocity in fps, *S* is the slope of the hydraulic gradient (channel bed slope in the case of uniform flow) ft/ft, and *n* is Manning's roughness coefficient (values are found in most hydraulic handbooks). The hydraulic radius *R* is defined as the cross-sectional flow area divided by the wetted perimeter. The travel time for open channel flow is determined from Equation 19.20 using the velocity obtained from Manning's equation.

When computing the various components of the time of concentration, the values of the velocities must be carefully reviewed to determine whether they are realistic. Many assumptions made about the land characteristics (e.g., uniform ground slope, vegetation height, and stream channel geometry) may give unrealistic values. For example, in natural open channels, the critical velocity should be considered as the limiting velocity.

Hydrographs. Runoff from a watershed is graphically shown by a hydrograph, which is a plot of the discharge as a func-

TABLE 19.11A Runoff Curve Numbers for Urban Areas[1]

COVER DESCRIPTION		CURVE NUMBERS FOR HYDROLOGIC SOIL GROUP			
COVER TYPE AND HYDROLOGIC CONDITION	**AVERAGE % IMPERVIOUS AREA[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved: curbs and storm sewers (excluding right-of-way)		83	89	92	93
Paved: open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-in sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
⅛ acre or less (town houses)	65	77	85	90	92
¼ acre	38	61	75	83	87
⅓ acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CNs are determined using cover types similar to those in Table 19.11c).					

[1]Average runoff condition and $I_a = 0.2S$. For range in humid regions, use Table 19.11b.
[2]The average percent impervious area shown was used to develop the composite CNs. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CNs for other combinations of conditions may be computed using Figures 19.14 or 19.15.
[3]CNs shown are equivalent to those of pasture. Composite CNs may be computed for other combinations of open-space cover type.
[4]Composite CNs for natural desert landscaping should be computed using Figure 19.14 or 19.15 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CNs are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Comparable CNs to use for the design of temporary measures during grading and construction should be computed using Figure 19.14 or 19.15, based on the degree of development (impervious area percentage) and the CNs for the newly graded pervious area.
Source: USDA, TR-55.

TABLE 19.11B (*Continued*)

Cover Description: Cover Type	Hydrologic Condition[1]	Curve Numbers for Hydrologic Soil Group: A[2]	B	C	D
Pasture, grassland, or range-continuous forage for grazing[1]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow-continuous grass, protected from grazing and generally mowed for hay	—	30	58	71	78
Brush-brush-weed-grass mixture with brush the major element[2]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[3]	48	65	73
Woods-grass combination (orchard or tree farm)[4]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods[5]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[3]	55	70	77
Farmsteads-buildings, lanes, driveways, and surrounding lots	—	59	74	82	86

[1]Poor: <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.
[2]Poor: <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
[3]Actual curve number is less than 30: use CN = 30 for runoff computations.
[4]CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.
[5]Poor: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately over the soil.
Source: USDA, TR-55.

tion of time. In the most simplistic case, a hydrograph has a rising limb that reflects rainfall characteristics, a crest segment, and a recession curve that reflects watershed characteristics. A hydrograph may be classified as a natural hydrograph, one that is derived from observed data from a stream flow gauge, or it may be classified as a synthetic hydrograph, one that is derived from presumed characteristics related to the rainfall and the watershed. The area under a runoff hydrograph represents the volume of runoff from the watershed.

The following parameters define the timing aspects of the hydrograph (see Figure 19.17):

- *Time to peak* (t_p), the time from beginning of runoff to the peak.
- *Lag time* (t_L), the time from center of mass of rainfall excess to the peak rate of runoff.
- *Time of concentration* (t_c), the time of equilibrium of the watershed. On a hydrograph, t_c is the time from the end of excessive rainfall to the inflection point on the recession limb.
- *Time base* (T_B), total duration of the direct runoff hydrograph.

As might be deduced from the hydrograph sketch and the definitions, the hydrograph shape is affected by the intensity, duration, and distribution (both temporally and spatially) of rainfall, by the size and shape of the watershed, and by factors that influence the time of concentration (land slope, channel length, and land cover/use). A short time of concentration results in a higher peak discharge rate and a shorter time to peak, while a long time of concentration results in a lower peak discharge rate and

TABLE 19.11C (*Continued*)

COVER DESCRIPTION		CURVE NUMBERS FOR HYDROLOGIC SOIL GROUP			
COVER TYPE	HYDROLOGIC CONDITION[1]	A[2]	B	C	D
Herbaceous-mixture of grass, weeds, and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen-mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper-pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub-major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

[1]Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: >70% ground cover.
[2]Curve numbers for group A have been developed only for desert shrub.
Source: USDA, TR-55.

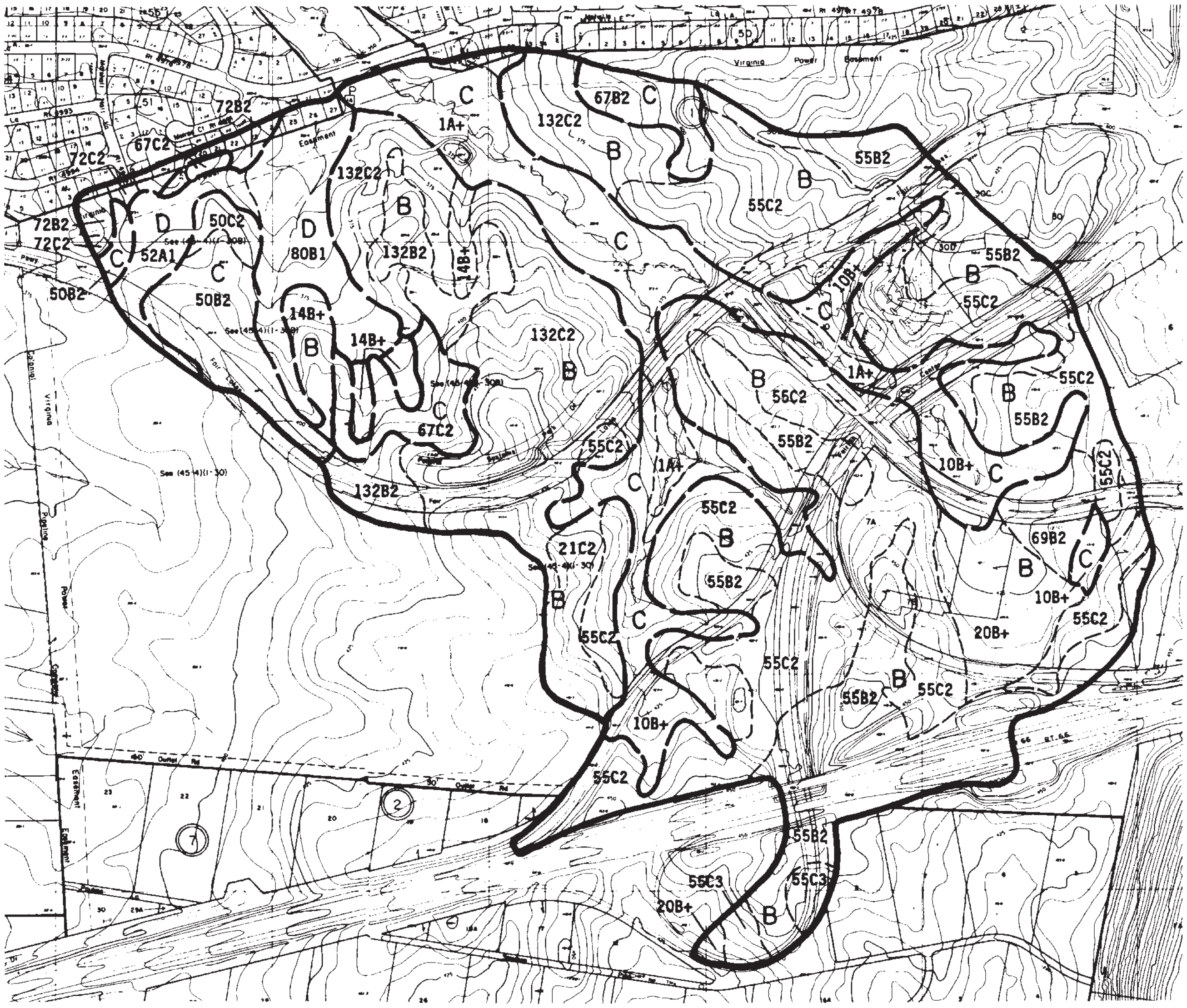
longer time to peak. These concepts are illustrated in Figure 19.18.

Generally, land development activities will decrease the time of concentration and increase the imperviousness for a basin. These changes decrease the time to peak discharge as well as increase the peak discharge and the total runoff volume; it is these increases that must be mitigated with stormwater management methods. A low-impact development (LID) or sustainable design approach to stormwater management seeks to replicate the predeveloped hydrologic conditions and reduce these inherent increases related to site development. By employing a variety of SWM techniques or other site features that maintain or even elongate the time of concentration or improve the land cover condition, the structural SWM facilities required can be minimized—see "Stormwater Management Facility Design" later in this chapter and Chapter 22 for additional guidelines on stormwater management facility design.

Unit Hydrographs. A unit hydrograph (UH) is defined as a runoff hydrograph generated from a unit depth of rainfall excess occurring at a constant rate over a specified duration of time, uniformly distributed over the watershed. The area under a unit hydrograph represents one unit of runoff depth over the entire watershed. Each unit hydrograph has a specific duration, that is, a time base, which represents the duration of the rainfall excess. Therefore, a D-hour unit hydrograph is defined as the hydrograph that results from a storm with a constant rainfall excess of 1 inch over a duration of D hours (see Figure 19.19).

The physical features of a watershed vary little from storm to storm. Therefore, in unit hydrograph theory, a storm event of equal duration but different intensity produces a direct runoff hydrograph with an equal base length and shape similar to that of a unit hydrograph. If the ordinates of the direct runoff hydrograph are proportional to runoff volume, multiplying the ordinates of a unit hydrograph by the rainfall intensity generates a hydrograph corresponding to that intensity.

For more complex unit hydrographs, generate direct runoff hydrographs through multiplication-translation-addition procedures (convolution) to obtain the direct runoff hydrograph. This can be done only if the assumptions of linearity are valid, that is, the time base remains constant regardless of the runoff depth. Figure 19.19 shows how to obtain a direct runoff hydrograph using the multiplication-translation-addition procedure.



HYDROLOGIC SOILS GROUPS

CONVERSION OF SOIL TYPES TO SOIL GROUPS					
SOIL TYPE	SOIL NAME	SOIL GROUP	SOIL TYPE	SOIL NAME	SOIL GROUP
1	Mixed Alluvial	C	52	Elbert	D
10	Glenville	C	55	Glenelg	B
14	Manassas	B	67	Penn	C
20	Meadowville	B	69	Enon	B
21	Manor	B	72	Bucks	B/C
32	Mayodan	B	80	Croton	D
50	Iredell-Mecklenburg	C/D			

Figure 19.15 Hydrologic soils designation on topographic mapping.

Worksheet 2: Runoff curve number and runoff

Project ______________________ By ____________ Date ____________

Location ______________________ Checked ________ Date ____________

Circle one: Present Developed ______________________________

1. Runoff curve number (CN)

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1]			Area ❐ acres ❐ mi² ❐ %	Product of CN x area
		Table 15-1	Fig. 2-3[2]	Fig. 2-4[2]		
				Totals =		

$$\text{CN (weighted)} = \frac{\text{total product}}{\text{total area}} = \_\_\_\_ = \_\_\_\_\_\_ ;$$

Use CN = ☐

2. Runoff

	Storm #1	Storm #2	Storm #3
Frequency.......... yr			
Rainfall, P (24-hour).......... in			
Runoff, Q .... in			

FIGURE 19.16 Runoff curve number worksheet. (Source: TR-55)

TABLE 19.12 Roughness Coefficient for Sheet Flow

Surface Description	n*
Smooth surfaces (concrete, asphalt, gravel, or bare soil)	0.011
Fallow (no residue)	0.005
Cultivated soils:	
Residue cover ≤20%	0.06
Residue cover >20%	0.17
Grass:	
Short grass prairie	0.15
Dense grasses†	0.24
Bermuda grass	0.41
Range (natural)	
Woods:‡	
Light underbrush	0.40
Dense underbrush	0.80

*The *n* values are a composite of information compiled by Engman (1986).
†Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
‡When selecting *n,* consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.
Source: USDA, TR-55.

Mathematically the ordinates for the direct runoff hydrograph for a complex storm pattern are found by:

$$\begin{aligned} q_1 &= p_1\, u_1 \\ q_2 &= p_2\, u_1 + p_1\, u_2 \\ q_3 &= p_3\, u_1 + p_2\, u_2 + p_1\, u_3 \\ q_4 &= p_4\, u_1 + p_3\, u_2 + p_2\, u_3 + p_1\, u_4 \\ q_5 &= p_5\, u_1 + p_4\, u_2 + p_3\, u_3 + p_2\, u_4 + p_1\, u_5 \\ &\vdots \end{aligned} \qquad (19.22)$$

where q is the runoff hydrograph ordinate, p is the rainfall excess ordinate, and u is the unit hydrograph ordinate. If n_p = the number of rainfall excess ordinates and n_u = the number of unit hydrograph ordinates, the number of direct runoff hydrograph ordinates $n_r = n_p + n_u - 1$.

In matrix format, Equation 19.22 is written as:

$$[Q] = [P][U]$$

$$\begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ q_4 \\ q_5 \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} = \begin{bmatrix} p_1 & 0 & 0 & 0 & 0 & 0 & \dots \\ p_2 & p_1 & 0 & 0 & 0 & 0 & \dots \\ p_3 & p_2 & p_1 & 0 & 0 & 0 & \dots \\ p_4 & p_3 & p_2 & p_1 & 0 & 0 & \dots \\ p_5 & p_4 & p_3 & p_2 & p_1 & 0 & \dots \\ \cdot & & & \cdot & & & \\ \cdot & & & \cdot & & & \\ \cdot & & & \cdot & & & \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ \cdot \\ \cdot \\ \cdot \end{bmatrix} \qquad (19.23)$$

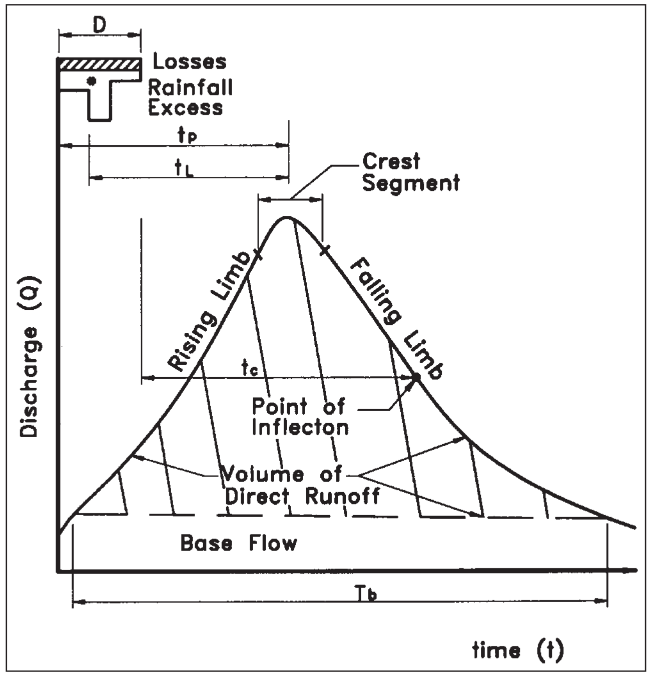


FIGURE 19.17 Elements of a hydrograph.

Generally, synthetic unit hydrographs are used to estimate the rainfall-runoff pattern for the design storm for a watershed. Synthetic unit hydrographs are often published in state or local design guides. If local design guides do not specify a hydrograph method, one of several synthetic hydrograph methods may be used. Popular methods for developing synthetic unit hydrographs include the NRCS method and the modified rational formula, Snyder's unit hydrograph, Clark's unit hydrograph, and numerous others.

The NRCS Dimensionless Unit Hydrograph. The NRCS and others have developed natural unit hydrographs from data collected from catchments of widely varied sizes and locations, which were then converted to an "average" synthetic curvilinear dimensionless unit hydrograph, shown in Figure 19.20. This is usually done in relatively small geographic regions where significant hydrologic data exists—for exam-

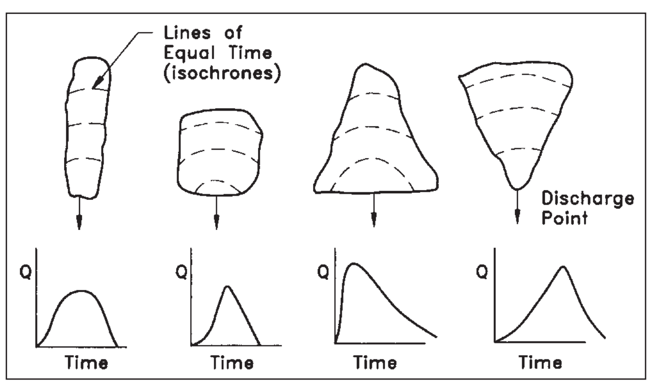


FIGURE 19.18 Effect of basin shape and t_c on hydrograph shape. (Courtesy of Wanielista, Martin P. *Hydrology and Water Quality Control.* New York: John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.)

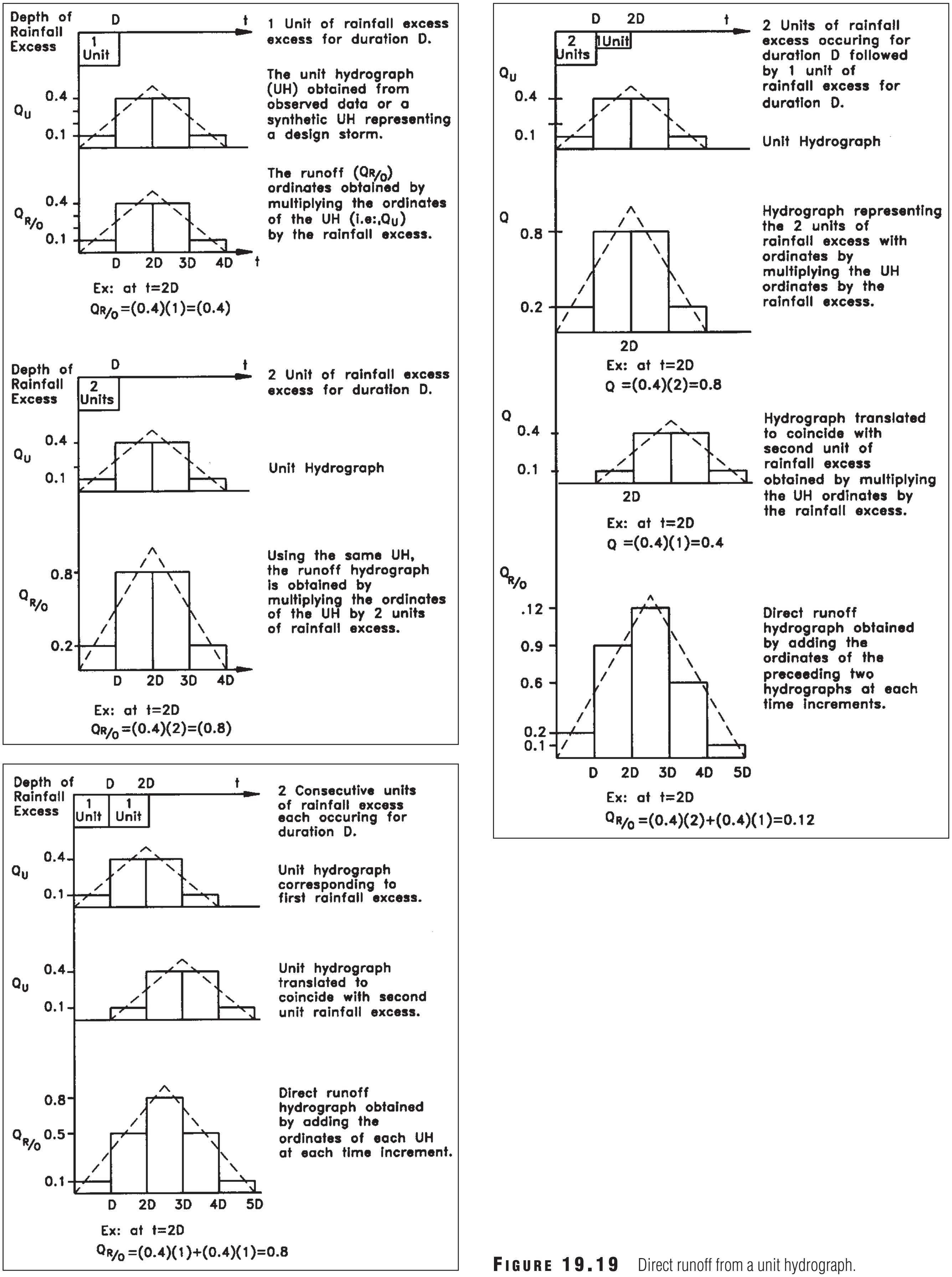


FIGURE 19.19 Direct runoff from a unit hydrograph.

ple, on the Delmarva peninsula. The engineer should contact the local NRCS office to confirm the applicable unit hydrograph. To simplify calculations, the curvilinear UH may be approximated by a triangular UH with similar characteristics. The base of the triangular UH is 8/3 of the time to peak compared with 5 for the curvilinear hydrograph. However, the area under the rising limb of both hydrographs is identical. The unit hydrographs are normalized (made dimensionless) by expressing the discharge as a fraction of the peak discharge (q/q_p), and the time values as a fraction of the time to peak (t/T_p).

With respect to the triangular UH, the total runoff volume Q, in inches, is:

$$Q = \frac{1}{2} q_p (T_p + T_r) \tag{19.24}$$

where q_p is the peak discharge (in/hr), T_p is the time to peak (hr), and T_r is the recession time (hr), which can be rewritten as:

$$q_p = \frac{484AQ}{T_p} \tag{19.25}$$

where q_p is the peak discharge for the unit hydrograph, A is drainage area in square miles, and 484 is included to place ⅜ of the area under the hydrograph under the rising limb. Changing the rising side of the UH to reflect watershed topography requires a change in the 484 peak rate factor. The peak rate factor has been known to vary from 600 for mountainous regions to 200 in very flat swampy areas. The local NRCS office should be contacted to determine whether a regional shape factor exists.

From the relationship of the triangular hydrograph to the storm duration, T_p can be expressed in terms of duration of unit rainfall excess and the time of concentration as:

$$T_p = \frac{D}{2} + 0.6t_c = \frac{2}{3}\,t_c \tag{19.26}$$

With proper substitution into Equation 19.25, q_p can be expressed in terms of t_c as:

$$q_p = \frac{726AQ}{t_c} \tag{19.27}$$

EXAMPLE 1

Determine the NRCS synthetic UH for a predominantly commercial catchment with the following characteristics: area = 200 acres, average land slope = 4 percent, t_c = 20 minutes, and HSG B.

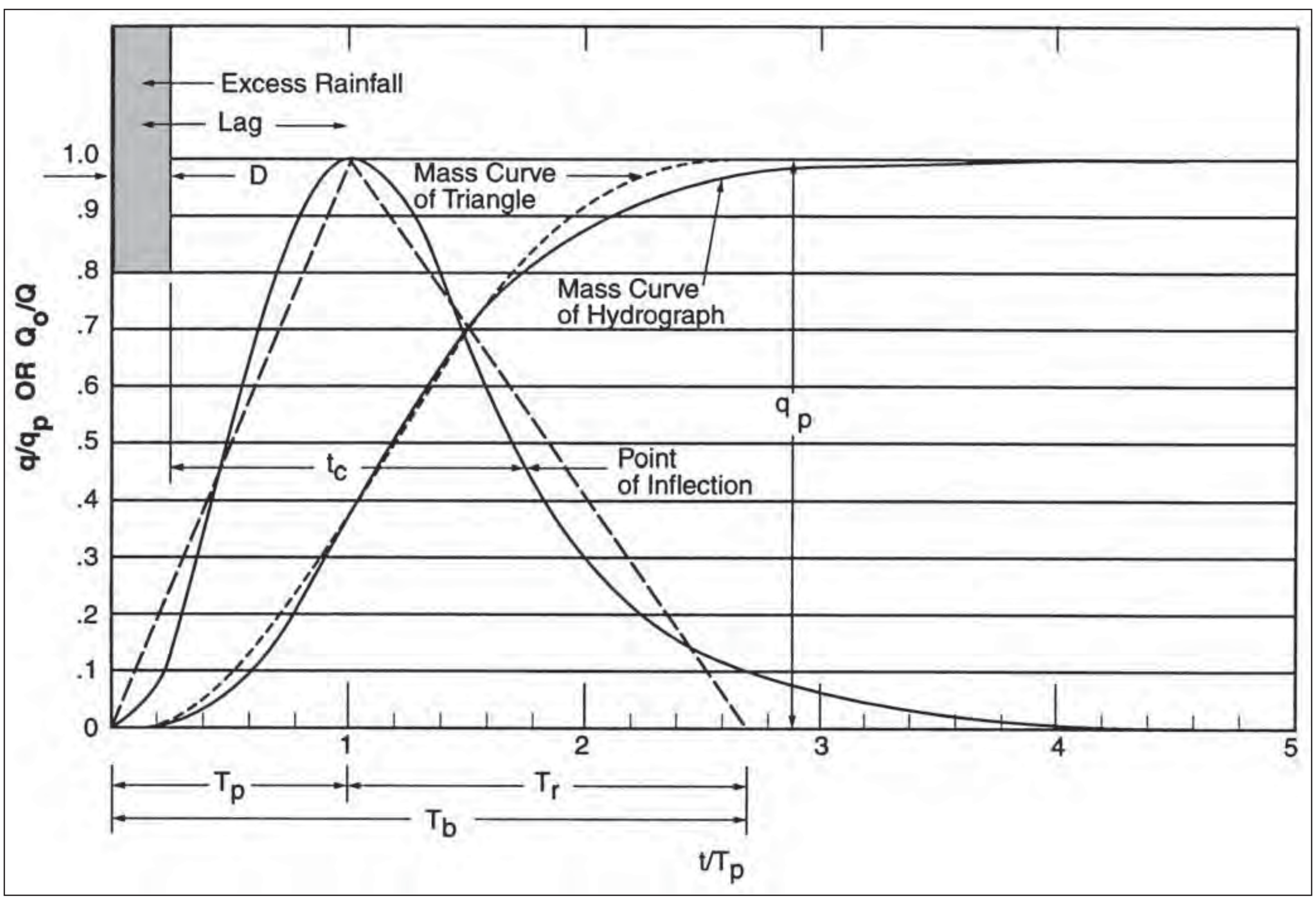


FIGURE 19.20 Dimensionless curvilinear UH with NRCS's triangular UH. (*Source:* USDA, NEH-4.)

From Table 19.11, the CN for commercial land use and HSG B is 92. From Equation 19.27, the peak discharge for the UH is:

$$q_p = \frac{726\ (200\ \text{ac})\ (1\ \text{in})}{(640\ \text{ac/mi}^2)\left(\dfrac{45\ \text{min}}{60\ \text{min/hr}}\right)} = 303\ \text{cfs} \qquad (19.28)$$

The time to peak is:

$$t_p = \frac{2}{3}\ t_c = \frac{2}{3}\ (20\ \text{min}) = 13.3\ \text{min} \qquad (19.29)$$

The time base is:

$$t_b = \frac{8}{3}\ t_p = \frac{8}{3}\ (13.4\ \text{min}) = 35.7\ \text{min} \qquad (19.30)$$

The triangular hydrograph is shown in Figure 19.21.

Computer Models for Rainfall-Runoff Relationships. Advances in computer software applications (CADD-based and otherwise) have made hydrologic modeling easier and quicker. Although many designers use these software programs as a "black box," it is recommended that users have some understanding of the hydrologic processes as well as knowledge of the fundamental limitations of the programs. The reliability of the output from any computer program is only as good as the input data, the inherent assumptions associated with the model, as well as the numerical techniques used to simulate the model. Blind application of the results can lead to poor design at best or jeopardize life and property at worst.

A number of computer models are available, well documented and supported, and powerful in terms of their ability to perform hydrology and manipulate hydrographs. These models may be used to generate hydrographs from either synthetic or historical design storms, combine hydrographs together, and perform storm drain design and channel and pond routings. The type of computer model selected depends on the user, available data, and, possibly, any preferences by the reviewing agencies.

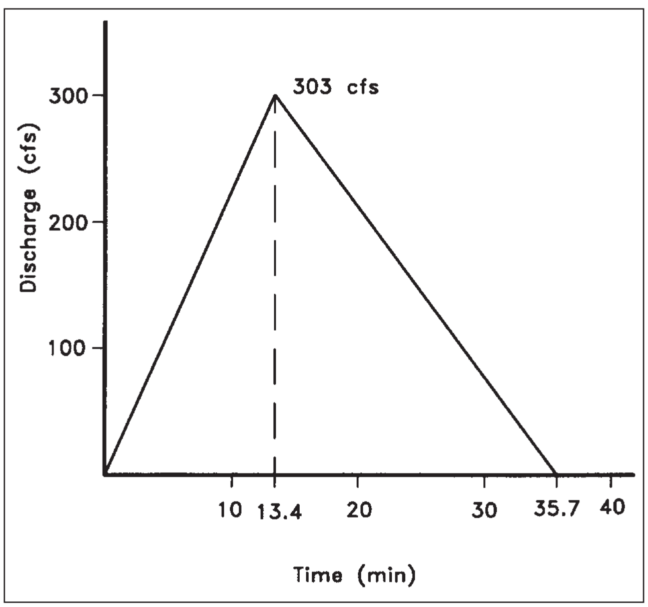


FIGURE 19.21 Synthetic triangular unit hydrograph for example.

Some of the more popular models in use are listed in Table 19.13.

NRCS Graphical Peak Discharge. A peak discharge can be obtained from a direct runoff hydrograph. When only a peak discharge is needed, the NRCS's graphical peak discharge method can be used instead of developing an entire hydrograph. NRCS's graphical method for determining the peak discharge, appropriate for homogeneous (i.e., uniform CN) watersheds and for 0.1 hr ≤ t_c ≤ 10 hr, is found by:

$$q_p = q_u A_m Q F_p \qquad (19.31)$$

where q_p = peak discharge (cfs), q_u = unit (hydrograph) peak discharge (ft^3/mi^2/in), A_m = drainage area (mi^2), Q = runoff (in, from Equation 19.16), and F_p = pond and swamp adjustment factor (from Table 19.14).

Before engaging in this method, consider the following limitations:

- The watershed should be homogeneous with respect to the CN.
- The weighted CN should be greater than 40, 0.1 ≤ t_c ≤ 10 hr, and 0.1 ≤ I_a/P ≤ 0.5.
- The watershed should have only one main channel. If there is more than one, all channels must have nearly equal t_c's.
- The method cannot perform reservoir or channel routing.
- The F_p factor is applied only for ponds or swamps, not in the t_c flowpath.

To compute the peak discharge for a watershed:

1. From appropriate maps obtain the 24-hour rainfall P for the design storm.
2. Determine the CN for the watershed.
3. Determine I_a from:

$$I_a = 0.2\left(\frac{1000}{\text{CN}}\right) - 10 \qquad (19.32)$$

4. The unit peak discharge (q_u) in cubic feet per square mile per inch of runoff is determined from:

$$\log(q_u) = C_0 + C_1 \log(t_c) + C_2[\log(t_c)]^2 \qquad (19.33)$$

where coefficients for C_0, C_1, and C_2 are given in Table 19.15 for I_a/P ratios. Figure 19.22 shows the graphical representation of Equation 19.33 for the NRCS type II rainfall distribution.

5. Determine the pond factor F_p, if applicable.
6. Use Equation 19.31 to find the peak discharge.

TABLE 19.13 Summary of Selected Computer Runoff Models

Attribute (1)	Model: DR3M-QUAL (2)	HSPF (3)	ILLUDAS (4)	Penn State (5)	Statistical (6)	STORM (7)	SWMM (8)	TR55 (9)	HEC-1 (10)
Sponsoring agency	USGS	EPA	III. State Water Survey	OWRT and City of Phil.[a]	EPA	HEC	EPA	SCS	HEC
Simulation type[b]	C, SE	C, SE	SE	SE	N/A	C	C, SE	SE	Se
No pollutants	4	10	None[c]	NONE	Any	6	10	None	None
Rainfall/runoff analysis	Y	Y	Y	Y	N	Y	Y	Y	Y
Sewer system flow routing	Y	Y	Y	N	N/A	N	Y	Y	Y
Full, dynamic flow routing equations	N	N	N	N	N/A	N	Y[d]	N	N
Surcharge	Y[e]	N	Y[e]	N	N/A	N	Y[d]	N	N
Regulators, overflow structures, e.g., weirs, orifices, etc.	N	N	N	N	N/A	Y	Y	N	N
Special solids routines	Y	Y	N/A	N/A	N	N	Y	N/A	
Storage analysis	Y	Y	Y	Y	Y[f]	Y	Y	Y	
Treatment analysis	Y	Y	N/A	N/A	Y[f]	Y	Y	N/A	
Suitable for planning (P), design (D)[g]	P, D	P, D	D	D	P	P	P, D	D	
Available on microcomputer	N	Y	Y	Y	Y[h]	N	Y	Y	
Data and personnel requirements	Medium	High	Low	Low	Medium	Low	High	Medium	
Overall model complexity[i]	Medium	High	Low	Low	Medium	Medium	High	Low	

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[a]Currently supported by Penn State University.

[b]Y = yes, N = no, N/A = not applicable, C = continuous simulation, SE = single event simulation.

[c]Undocumented quality routines added during applications.

[d]Full dynamic equations and surcharge calculations only in Extran Block of SWMM.

[e]Surcharge simulated by storing excess inflow at upstream end of pipe. Pressure flow not simulated.

[f]Storage and treatment analyzed analytically. See references in Section 3.7.9.

[g]See Section 3.3.

[h]See Driscoll et al. 1989.

[i]General requirements for model installation, familiarization, data requirements, etc. To be interpreted only very generally.

Reflection of general size and overall model capabilities. Note that complex models may still be used to simulate very simple systems with attendant minimal data requirements. Surcharge row, model column = Y[e], illudas column = Y[e], available column = Y[f].

TABLE 19.14 Adjustment Factor (F_p) for Pond and Swamp Areas that are Spread Throughout the Watershed

Percentage of Pond and Swamp Areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Source: USDA, TR-55.

Storm Drainage Design

Following the development of the general site layout and hydrologic analysis of the site, the horizontal placement and sizing of the storm drainage system are performed. Conveyance systems may vary from nonstructural systems such as vegetated filter strips, rain gardens, and swales to structural systems comprising pipes, culverts, and inlets. The selection of what type of components will constitute a system may vary due to many factors, including overall development objectives, such as low-impact development (LID) and green building objectives, available site area for such components, topography, soils, and sensitive area concerns, as well as local jurisdictional requirements. More and more jurisdictions are requiring consideration and implementation of LID techniques, nonstructural stormwater management strategies, and widely accepted best management practices (BMPs). The design engineer must evaluate and give consideration to these objectives and incorporate these various design elements as appropriate.

Once the type of conveyance and collection system has been established, these systems are incorporated into the site

TABLE 19.15 Coefficients for Determining q_u

Rainfall Type	I_a/P	C_0	C_1	C_2
I	0.10	2.30550	–0.51429	–0.11750
	0.20	2.23537	–0.50387	–0.08929
	0.25	2.18219	–0.48488	–0.06589
	0.30	2.10624	–0.45695	–0.02835
	0.35	2.00303	–0.40769	0.01983
	0.40	1.87733	–0.32274	0.05754
	0.45	1.76312	–0.15644	0.00453
	0.50	1.67889	–0.06930	0.0
IA	0.10	2.03250	–0.31583	–0.13748
	0.20	1.91978	–0.28215	–0.07020
	0.25	1.83842	–0.25543	–0.02597
	0.30	1.72657	–0.19826	0.02633
	0.50	1.63417	–0.09100	0.0
II	0.10	2.55323	–0.61512	–0.16403
	0.30	2.46532	–0.62257	–0.11657
	0.35	2.41896	–0.61594	–0.08820
	0.40	2.36409	–0.59857	–0.05621
	0.45	2.29238	–0.57006	–0.02281
	0.50	2.20282	–0.51599	–0.01259
III	0.10	2.47317	–0.51848	–0.17083
	0.30	2.39628	–0.51202	–0.13245
	0.35	2.35477	–0.49735	–0.11985
	0.40	2.30726	–0.46541	–0.11094
	0.45	2.24876	–0.41314	–0.11500
	0.50	2.17772	–0.36803	–0.09525

Source: USDA, TR-55.

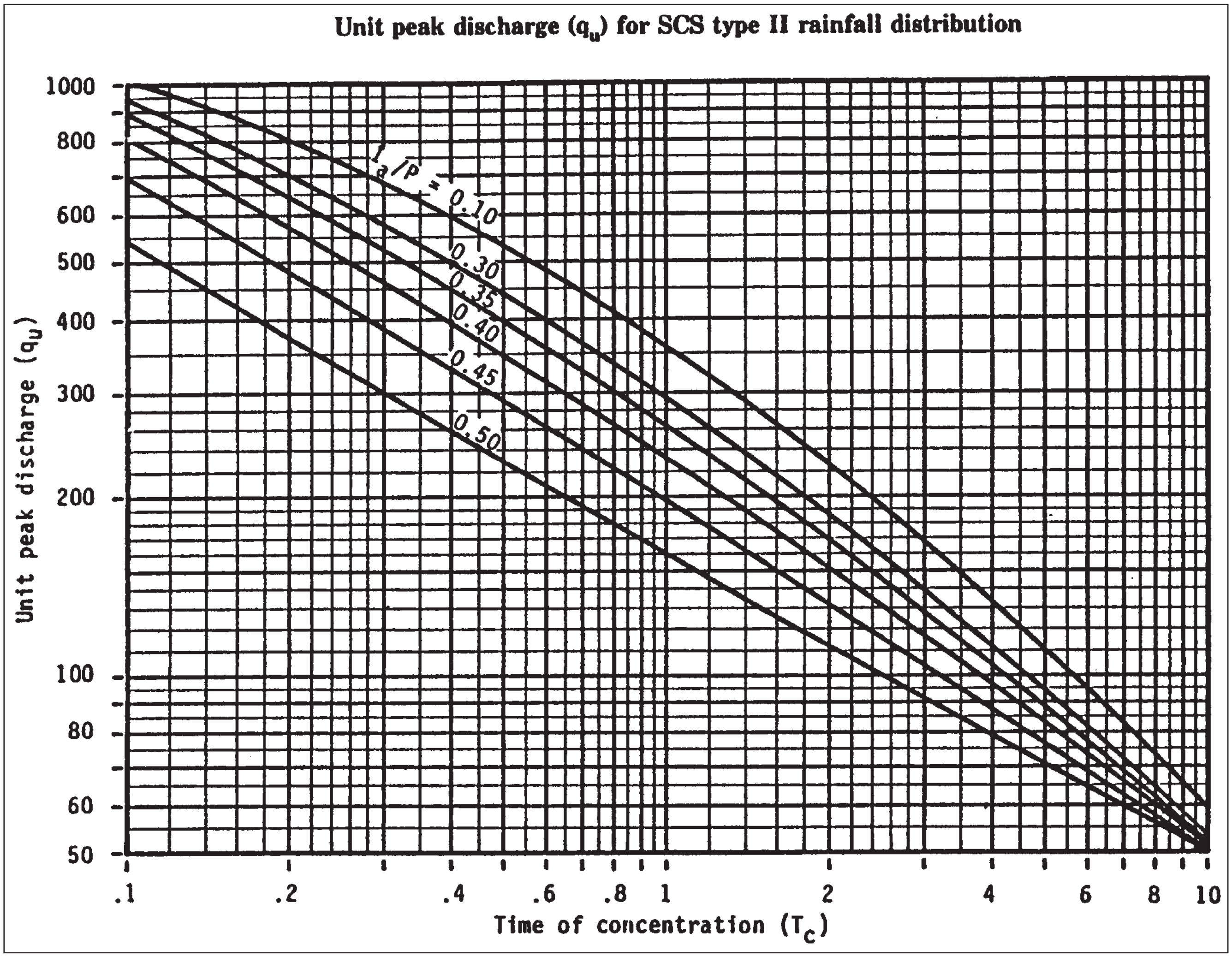

FIGURE 19.22 Unit peak discharge q_u for NRCS type II rainfall distribution. (*Source:* USDA, TR-55)

plan as the grading and drainage plan is developed. Preliminary sizing should be performed on each component to provide adequate conveyance of stormwater runoff to proposed stormwater management facilities or points of discharge (outfalls). It is important to verify the design storm and sizing requirements for these systems, with local authorities having jurisdiction. However, the designer must also account for safe runoff conveyance either via overland flow, via the collection system, or via other secondary means of conveyance for storm events exceeding the required design storm for the collection system. This is necessary to ensure the stormwater management facilities will actually receive the runoff from the higher-intensity storm events they are designed to attenuate. Typically, profiles of the storm sewer system are part of the final design; however, select profiling should occur during preliminary engineering to locate vertical conflicts with other utilities. Additionally, flow capacities of proposed and existing systems should be checked. Since the adequacy of the drainage outfalls is critical, as-built information of existing storm systems and field run cross sections of existing drainage channels (natural or man-made) should obtained.

Stormwater Management Facility Design

Designing stormwater management (SWM) facilities is part of the preliminary engineering stage of the design process. In order to size the facilities, it is important to determine the specific performance requirements for the facility. These may include water quality or pollution removal, ground water recharge, and quantity control (detention/retention) requirements for the proposed development. These requirements vary greatly from region to region within the country and even at the state and local levels. Although the exact configurations and grading of such facilities are subject to change during final engineering, it is important to ensure that adequate provisions have been made to accommodate and locate these facilities to achieve the required stormwater management objectives.

Stormwater management facilities are commonly grouped into several facility types, which are selected based on site considerations, performance requirements, aesthetics, and other factors (cost). These facilities usually fall into one of the following types:

- Detention basin (i.e., dry pond for the temporary impoundment of surface water runoff)
- Retention basin (i.e., wet pond that maintains a permanent pool of water with additional storage volume above the permanent pool for detaining runoff)
- Infiltration facilities
- Structural facilities

Exact design parameters for each of these facility types may vary depending on local requirements, and often combinations of these generalized facility types are used together to achieve performance goals. For instance, a stormwater management facility may employ infiltration of runoff as a means to provide ground water recharge and water quality functions, while providing controlled outflow for larger storms. Similarly, a wet pond may be used for water quality treatment in conjunction with extended detention to reduce peak runoff rates. If runoff volume control is required, the postdevelopment stormwater management program will have to include permanent storage facilities (retention), infiltration facilities, stormwater harvesting/reuse facilities (typically structural), or some combination of the three in order to minimize the total volume of runoff leaving the site. The designer must evaluate and determine the most appropriate facility or combination of facilities to achieve the applicable performance requirements.

Locating SWM Facilities. The location of SWM facilities should be integrated with the site design, either to minimize the impact on the development project or to enhance the development in terms of function and aesthetics. If possible, an SWM facility should be located so that runoff drains into it naturally, without requiring additional engineering measures such as storm sewers or channels to artificially force drainage divides. The most economical design for any SWM facility is one that requires the least earthwork and fewest structural components. Further, facilities should be located with respect to outfalls in order to maintain natural (existing) drainage divides as well as protect and improve the condition of outfalls through adequate capacity analysis and erosion reduction.

Preliminary Sizing of SWM Facilities. The basic steps for sizing and designing a stormwater management facility for water quantity control purposes are:

1. Determine facility location and type (e.g., retention or detention).

2. Develop inflow hydrographs for the design storms (predevelopment and postdevelopment). Localities may mandate that the facility must attenuate postdevelopment peak discharges for several design storms.

3. Determine maximum postdevelopment release rates based on local design standards.

4. Estimate the amount of storage required for each of the design storms (see "Estimating the Volume of Storage Required").

5. Grade earthen facilities or size (volumetrically) structural facilities to accommodate the necessary storage and develop stage-storage and stage discharge curves (see Chapter 22 for additional guidance).

6. Estimate water surface elevations (WSEs) for design storms (based on results from steps 4 and 5); determine freeboard (clear space above highest design storm WSE) requirements and design facility embankment (top of dam) or structural rooftop; assess feasibility of fully developed facility with grading design.

7. Select preliminary size and configuration of principal outlet control structure (risers, spillways, and/or clearwell arrangement).

8. Perform hydrologic routing computations to verify preliminary design features.

9. Based on results obtained in step 8, modify basin grading (or volumetric size) and outlet structure to optimize releases for various design storms.

10. Determine other design requirements (trash racks, antiseep collars, embankment seepage control elements, bypass structures, etc.) and the need for emergency overflow relief and design accordingly.

When sizing a water quality facility, the process can be simplified, as most water quality or BMP facilities are sized/designed based on a specific water quality volume (WQv). Depending on geography, climate, and jurisdictional requirements, the WQv usually ranges from 0.5 inch to 1 inch of rainfall per impervious acre. Once the facility location, type, and WQv are determined, design of the facility can proceed through steps 5, 7, and 10. Certain technology-based BMPs are sized/designed based on water quality storm flow rate as opposed to a WQv; these facilities should be sized according to manufacturer recommendations and any additional jurisdictional guidelines that specifically address the use of these BMPs. Additional guidance on SWM facility design is provided in Chapter 22.

Special consideration must be given to the spillway capacity of the stormwater management facilities, particularly in the case of dam embankments for surface facilities. Oftentimes the spillway capacity, which is related to the hazard classification of the facility, must be increased if the facility is found to be a hazard to downstream insurable structures. A hazard classification should be determined and, if necessary, a dam break analysis performed to analyze potential impacts downstream from the facility. Such analysis may determine that off-site easements are required downstream for a breach.

These easements will need to be pursued by the owner or developer.

Estimating the Volume of Storage Required. When initially sizing an SWM facility, the required storage volume to meet detention requirements is unknown. An initial estimate of the required storage volume may be made based on the inflow hydrograph and the required outflow rate. The amount of storage required for a given design storm is equal to the representative volume between the inflow and outflow hydrographs.

To obtain a first estimate of the storage required, the outflow hydrograph can be approximated by drawing a straight line from the beginning of substantial runoff on the inflow hydrograph to the point on the receding limb corresponding to the allowable peak outflow rate. Alternatively, TR-55 provides a dimensionless graph relating the ratio of storage volume to runoff volume to the ratio of peak outflow discharge to peak inflow discharge for the four types of synthetic storms (see Figure 19.23).

Once an initial estimate of the required volume has been made and the location determined, a preliminary grading plan (for earthen or surface facilities) or volumetric design (for structural or infiltration-based facilities) is performed. In preparing the grading plan, the objective is to obtain the preliminary storage volume while keeping in mind such things as minimizing earthwork, nominal height requirements of the embankment, depth and clear height (confined space) limitations for safety, sediment storage, aquatic vegetation, depth to ground water table, cost, and aesthetic considerations.

A graph of the stage-storage relationship is then developed. The stage-versus-storage relationship is derived by measuring the area within the pond or structure at selected elevations and estimating the storage volume based on the area and depth (and often, in the case of underground structural infiltration facilities, the void ratio of the media in conjunction with the structural storage). The areas can be measured with a planimeter on a contour map, with CADD software area measurement tools, or by other engineering methods for determining volume (see Chapter 23 for more information). Two different equations are commonly used to compute the volume: the average end area

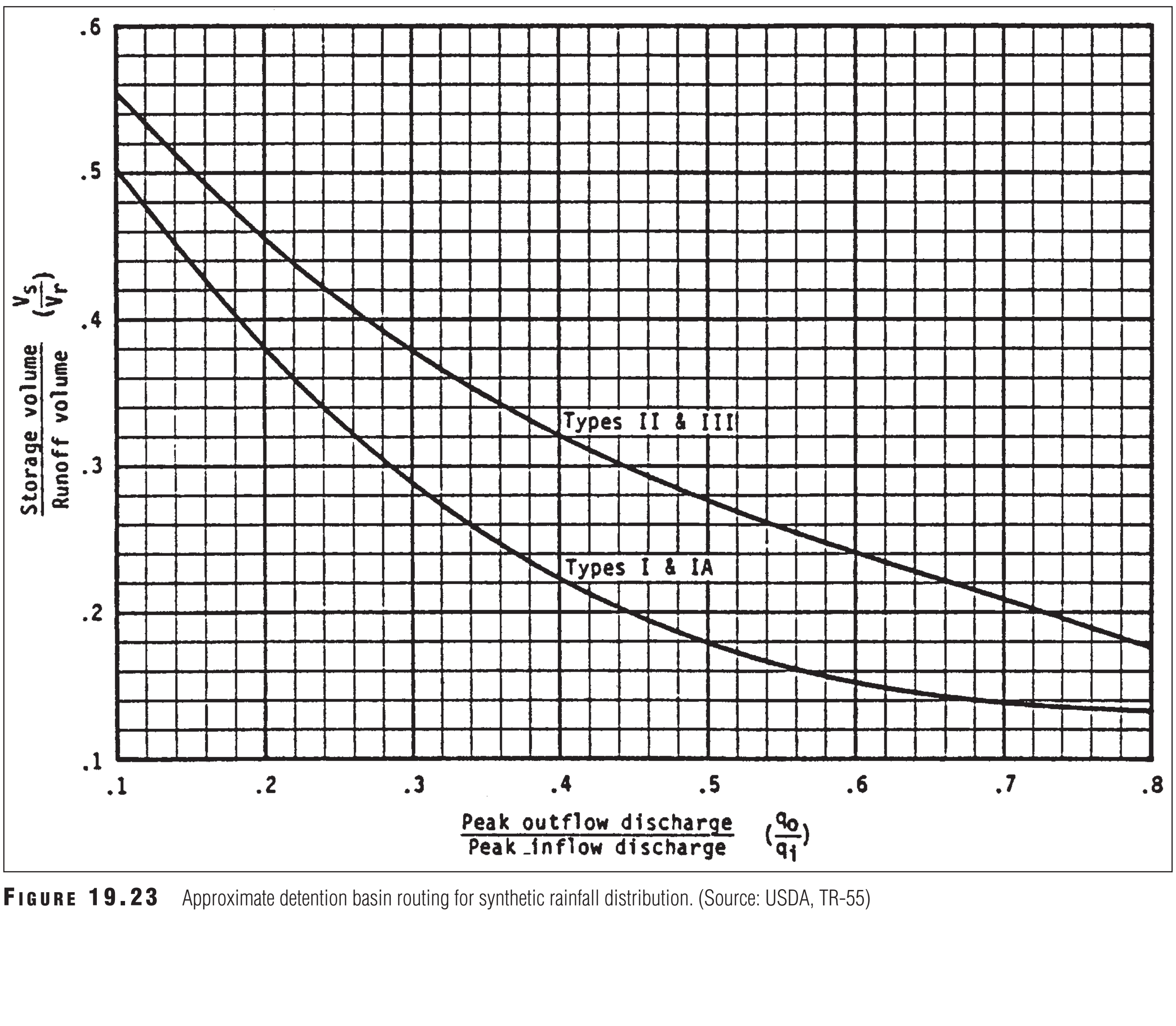

FIGURE 19.23 Approximate detention basin routing for synthetic rainfall distribution. (Source: USDA, TR-55)

method (Equation 22.19) and the conic approximation method (Equation 22.20). The conic approximation method is used in some computer methods such as HEC-1.

Average End Area Method:

$$V_{\text{inc}} = \frac{A_n + A_{n+1}}{2} \times h \tag{19.34}$$

Conic Approximation Method:

$$V_{\text{inc}} = \frac{A_n + A_{n+1} + \sqrt{A_n \times A_{n+1}}}{3} \times h \tag{19.35}$$

where V_{inc} = incremental volume in pond between contour lines representing A_n and A_{n+1}, A_n = measured area of nth contour line, A_{n+1} = measured area of the successive contour line, and h = elevation difference between the two contour lines.

Many stormwater management system design software packages are capable of performing preliminary sizing estimates for detention basins, utilizing these methods. They can be helpful in streamlining the evaluation of various basin and outlet device configurations.

Floodplain Studies

Existing floodplains that were approximated during the feasibility and site analysis stage of design should be analyzed and modeled using field-run topography to determine the extent of the floodplain. These floodplains should be brought in to the base map to more accurately identify their expanse. The specific details of floodplain analysis are presented in Chapter 18.

Grading and Earthwork

Site grading is one of the most important steps of the preliminary engineering process. It determines the extent of the clearing limits of the project and determines whether any requirements for off-site construction are needed. Earthwork analyses can be performed using the preliminary grading plan to check whether the proposed project balances or will require the import of fill or export of cut.

Prior to initiating work on the grading plan, the design engineer should review soils mapping and/or available geotechnical reports to understand and evaluate existing site and soil conditions. These investigations should include a review of information regarding problem soils, ground water levels, rock formations, suitability of on-site soils for reuse, and other conditions that might affect the grading design.

Grading Strategy. Once site and street geometrics have been refined and gravity utilities tentatively arranged, it is time to develop a grading plan. The grading design can be broken down into various areas of the site including roadways, stormwater management areas, building pads, open-site areas, areas to remain undisturbed, buffer areas, and parking areas. Each area presents its own specific requirements that need to be evaluated against the existing site conditions. Grading experience makes most considerations second nature and enables the designer to concentrate on an overall strategy that produces the best possible plan.

Perhaps the most important aspect of grading is to ensure proper drainage of the site. If water is trapped, flows toward undesirable locations, or causes erosion, the grading has failed in its most basic requirement. The design engineer must take into account site-generated runoff as well as runoff that flows onto the site from off-site areas. The drainage shed analysis serves as the basis for the design of all the proposed drainage structures and often influences the very layout of the site plan. The drainage study sets the basic parameters for the grading design. The following is a list of goals for a site grading plan from a drainage perspective:

- Collect runoff and direct it safely to adequate outfall points at nonerosive velocities.
- Quickly convey runoff away from buildings to protect them from foundation damage and wet basements.
- Prevent the formation of unintentional wet areas that cause maintenance problems.

Both experience and imagination play a role in developing the grading scheme. As the designer begins to work through the process, relationships between proposed improvements and existing conditions begin to coalesce. Important relationships begin to dictate patterns, such as existing elevations at site entry points compared to ground elevations at proposed building sites.

Drainage is conveyed either overland or underground. Overland flow in its most benign form is called sheet flow, where little or no concentration of water exists as it moves across uniform, fairly level areas. Sheet flow is an ideal way to convey water because it helps absorption and is nonerosive. However, it is difficult to maintain sheet flow for large areas or over long distances, due to water's tendency to concentrate. Left on its own, water quickly gathers into swales and ditches. The designer's job is to artfully manipulate this transition from sheet flow to shallow concentrated flow using sound engineering principals that accomplish the goal without cluttering the site with drainage system components. Although it may be possible to direct all runoff to its outfall points via overland flow on a small site (i.e., a single residential lot or small commercial site), it is usually necessary to collect and pipe it underground on larger development sites. Detailed design methodologies for storm sewer conveyance systems are presented in Chapter 21 and should be referred to for additional clarity needed beyond the schematic design phase.

Guiding the designer are general rules of thumb that help simplify the process. A basic premise of grading is that a minimum slope of 0.5 percent needs be maintained to drain runoff across paved surfaces and 2 percent needs to be maintained to drain runoff across nonpaved areas. Decreasing the slope below these recommendations may result in sluggish drainage and standing water. Construction delays could also occur: very flat slopes are difficult to achieve in the field, even given the precision of modern construction equipment. Flat areas also remain wet for a longer period of time, which may cause construction delays following rain. Yet site constraints often require slopes less than those recommended; thus, they are not entirely uncommon. The use of flat slopes should be carefully considered and simply avoided if possible.

In some instances, the minimum desirable slope exceeds 2 percent, such as the grading adjacent to a building, where the objective is to move the water away quickly. The ground elevation at the building is referred to as the parge grade.[3] Dropping the proposed elevation at least 6 inches below the parge grade within the first 10 feet of the building (5 percent) is ideal. Figure 19.24 shows the three basic methods for directing surface drainage away from a building. The ground beyond the parge grade directs the runoff to eventual points of collection. Although grades can vary beyond this point, a minimum slope of 2 percent helps prevent drainage problems.

Conversely, proposed grades that are too steep can lead to erosion and maintenance concerns. Steep slopes increase the velocity of water and therefore its energy, so that even relatively small amounts of runoff can erode large quantities of mulch or soil off a hillside. If grass is established on the slope, mowing is dangerous if slopes exceed 3H:1V. While slope stability depends on many factors, they are all exacerbated with steeper slopes, especially in a fill condition. Local policy may also dictate the maximum (and minimum) slopes required for specific situations, which makes a working knowledge of pertinent ordinances a valuable tool.

Minimum and maximum slopes are also an important consideration when designing roads, driveways, parking areas, sidewalks, and trails. Road design is a science unto itself, and the grading of roads as well as pedestrian and bicycle facilities, usually closely tied to road grades, is explained in Chapter 20. Pedestrian facilities, especially those subject to accessible design criteria, require special attention. Accessible routes should be identified and preliminarily graded at this stage in the design process to ensure compliance with applicable federal regulations, and where conflicts become evident, alternative options should be investigated.

Grading and Aesthetics. Drainage considerations form the basis of functionally sound grading; however, function is usually not enough in the competitive world of land development. A site must appeal to a user's aesthetic sense in order to be successful. Grading can transform a flat, featureless site into a visually pleasing series of rolling landforms that enhances the consumer's experience and creates a higher demand for the property.

Figure 19.25 illustrates how grading can be used to enhance aesthetics. The grading itself can become the feature, as in the creation of landforms where none exist (19.25*a*). Grading can also be used to influence what we see, by hiding a visually undesirable element, as shown in 19.25*b*, or opening up a view, shown in 19.25*c*. The landforms created for aesthetic reasons can simultaneously serve functional roles. The landform may aid in the balancing of earthwork by providing an on-site location to dispose of excess soil or be used to direct wind away from buildings or outdoor use areas.

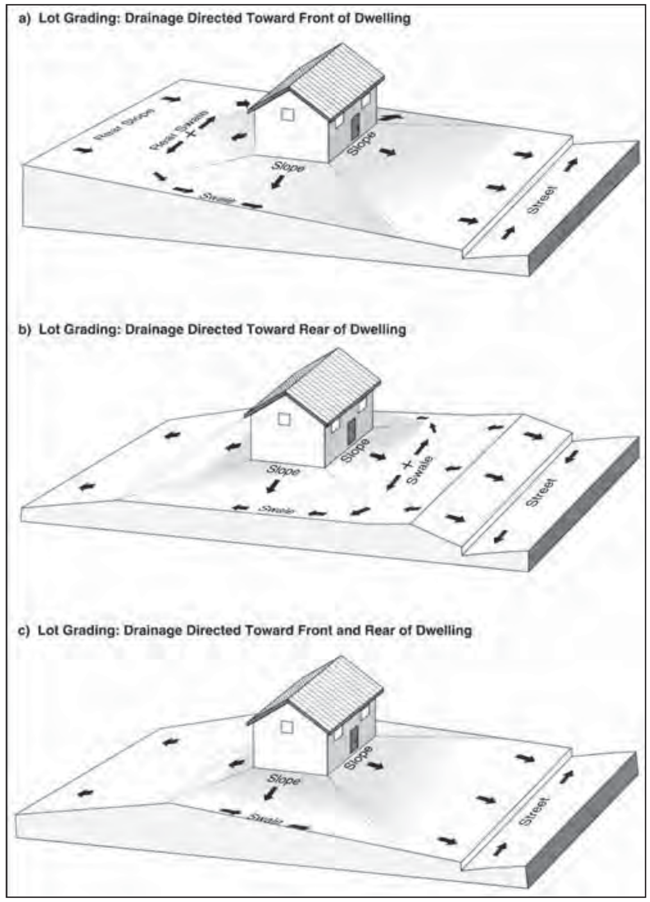

FIGURE 19.24 Three basic grading schemes for drainage around a building.

However, using the grading to enhance the site aesthetically is not achieved by simply following formulas and rules; it must be coupled with a thorough knowledge of the site and the sensitivity to know what will work. Whereas a 20-foot berm on one site is appropriate, it might be totally inappropriate on another. Similarly, a small retaining wall used to help save a grove of trees may serve as the signature design element for a new project. Because most of these grading devices have an impact on project costs, the aesthetic gain must be compared to the extra construction expense. Sometimes the designer can justify the expense, but he or she must be prepared with lower-cost solutions if necessary.

Schematic Grading Analysis. Before detailed grading plans are under way, the designer should develop a schematic or preliminary grading scheme to determine any problem areas and to identify grading opportunities and constraints that will need to be addressed through the remainder of the

[3]A coat of masonry cement (parge) is applied to the part of the building walls below grade as a deterrent for moisture penetration. The parge grade is the elevation of the ground around the building sufficient to cover the parge coating.

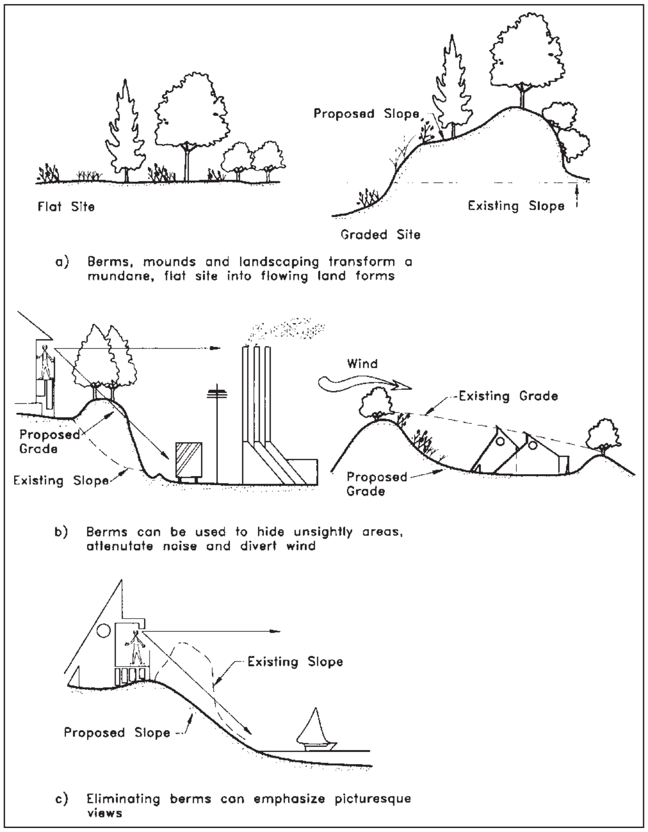

FIGURE 19.25 Grading to improve aesthetics. (Courtesy of Nelischer, Maurice, ed. *Handbook of Landscape Architectural Construction,* vol. 1, 2nd ed. Washington, DC: Landscape Architecture Foundation, 1985)

design progresses. Developing a schematic grading plan consists of utilizing the schematic layout to confirm the placement of building footprints and set the building elevation(s), road grades, and parking area grades. Spot elevations and sketching the 5-foot, or sometimes 2-foot, contour lines helps to determine the feasibility of the building elevations. Often the initial grading plan or general approach to the site grading scheme is flushed out by hand; it is then further refined, detailed, developed, and digitized using CADD software applications to establish geometrically correct alignments and digital terrain models (DTMs) for further analysis.

The following checks should be performed on the preliminary grading scheme in order to gauge functionality and aesthetic performance:

- Drainage patterns are analyzed.
- Rough estimates of cut and fill quantities are calculated (see Chapter 23 for detailed methodology).
- The need for steep slopes and retaining walls is determined.
- Tree-save and other sensitive (environmentally or historic) areas are identified.
- Limits of clearing and grading are defined.

During this process, several grading schemes may result, each with its own advantages. Conferring with the client may help in establishing the preferred grading scheme to pursue in final design.

Wastewater Collection and Treatment

Generally there are two common types of wastewater collection and treatment methods implemented on land development projects: individual subsurface disposal systems (septic systems) and public collection and treatment systems. A less common third type of system is a private community system that may utilize subsurface disposal or small, oftentimes packaged, treatment plants. Ordinarily the decision as to which type of system will be utilized to serve the development is made during the feasibility stage along with a determination as to whether sufficient capacity is available if utilizing public collection and treatment systems.

During the preliminary engineering phase, the design of the collection system begins with a projection of anticipated sewage flow. These calculations may be based on regulatory requirements for projected flows, historical data obtained from similar sizes and types of facilities, or other accepted reference sources (see Chapter 24 for additional information on sewage generation estimating). It is important for the design engineer to recognize that the system must be designed according to anticipated capacity requirements as well as regulatory requirements, either of which may end up governing the design. It is preferable for sanitary sewer collection systems to be gravity systems to the maximum extent possible, to eliminate the increased cost and maintenance of pumping facilities. It is also important to evaluate and assess the potential need for future expansion of the new system and make appropriate accommodations if this is anticipated to occur. If the collection system will be tied into an existing system, as-built information on the downstream system should be evaluated as part of the design. Profiles of the sanitary sewer are normally part of final design; however, select profiling should occur during preliminary engineering to locate vertical conflicts with other utilities and determine whether there is adequate cover over pipes such as at stream crossings and in roadways. Many jurisdictions require minimum clearances, cover, separation, and, occasionally, encasement of sanitary collection systems from other utilities and in areas such as stream crossings.

If a pump station is required to convey sanitary flow, a detailed analysis of the various options for placement of the station and the route of the gravity collection piping as well as the forcemain should be performed in the feasibility stage. In the preliminary engineering phase, the pumping station needs to be sized based on anticipated flows, allowable residence time, cycle length, and required wet well depth. Careful consideration must be given to construction feasibility and cost associated with each element of the pumping station.

In the feasibility phase, downstream treatment plants should be contacted to confirm that they have capacity for the proposed flows from the development. If public sanitary sewer is not available to the project, alternative methods for wastewater treatment need to be explored in the preliminary engineering phase. As an example, if septic systems will be used for sewage treatment, they should be preliminarily sized and configured. In order to do this, percolation tests in the area of the disposal fields must be performed to determine the rate at which the soil can absorb the effluent. The tests (including number and location) need to be coordinated with the geotechnical engineer and must be performed per the applicable regulatory requirements.

Water Supply and Distribution

Water supply is ordinarily facilitated by either connection of the development to a public water distribution system or installation of an on-site ground water supply well. In most cases, it is preferable to provide a connection to public water supply if it is available to the site or can be extended to serve the site at a reasonable cost. Again, the decision as to which type of system will be utilized to serve the development is made during the feasibility stage along with a determination as to whether sufficient capacity for fire and domestic flow is available from the existing water system.

The preliminary water supply system design begins with a projection of anticipated domestic and fire flow demands. These calculations may be based on regulatory requirements for projected flows, historical data obtained from similar sizes and types of facilities, or other accepted reference sources. The potential need for future expansion of the new system should be considered and appropriate accommodations made if this is anticipated to occur. The horizontal configuration of the water supply system should be determined. Water system pressures in the immediate vicinity of the proposed development should be checked as well as available fire flows.

If the site will be served by an onsite water supply well, borings and pumping tests must be performed to verify available capacity.

Erosion and Sediment Control

During any site development project, it is critical to develop a comprehensive soil erosion and sediment control plan to be implemented to prevent erosion and the off-site migration of sediments. Most states require the preparation of a Storm Water Pollution Prevention Plan (SWPPP) as part of every construction project that involves land-disturbing activities. A general erosion and sediment control program should be determined at this stage of the design program to ensure compliance with local code requirements. Some jurisdictions review and approve rough grading/erosion and sediment control plans so the developer/builder can begin site construction while preliminary and/or final engineering efforts are still under way.

Typical elements of most erosion and sediment control plans include stabilized construction entrances; temporary sediment barriers such as silt fence, stormwater inlet filters, temporary sediment ponds, runoff diversions and check dams; dust control measures; temporary stockpile and soil stabilization; and permanent measures such as permanent vegetative cover, conduit outlet protection, slope stabilization, or armoring. Many nonstructural design elements should also be incorporated into these plans, including minimizing site disturbance during construction, minimizing soil compaction in vegetated areas to reduce runoff, and protecting environmentally sensitive areas, such as wetlands, by establishing adequate buffers from construction activities. Careful consideration of erosion and sediment (E&S) controls at this phase of the design is critical to understanding the construction process for the proposed development program and developing a construction sequence or project phasing that respects the constraints of the site while still providing sufficient space and reasonable time frames for requisite construction activity. Planning for and performing the preliminary design of E&S controls will help to minimize erosion and construction runoff pollution as well as clarify critical areas requiring greater attention during final engineering.

Dry Utility Design

Most development projects require various dry utility services such as natural gas, electrical distribution, and telephone and data communications services. Availability of these services should be determined in the feasibility phase. It may be necessary to contact the utility providers during the preliminary engineering phase to determine the limits of design responsibility, upgrades that may be necessary, and load information that will be required to perform final design and engineering of the these systems. Additional information on designing these facilities is included in Chapter 26.

Cost Estimating

Preliminary cost estimates of the proposed site improvements, including the permitting or regulatory fees associated with the development program, can be determined at this stage of the project once the preliminary engineering design is complete. Such costs can be approximated using nationally published reference manuals or the local governing agency pricing guidelines. Oftentimes developers/builders have a database of cost guidelines they may wish to utilize or they use previously designed and built projects for unit price costs. These preliminary estimates are important for the developer to review in order to ensure the project costs are in line with expectations. At this stage of design, it is appropriate for the design engineer to include some level of design and construction contingencies in these estimates, to account for additional costs that may not be clarified until after the final design is complete. See Chapter 29 for additional guidance on estimate preparation.

Regulatory Permitting

Engineers, planners, and most members of the land design team appreciate the complexity involved in the design and construction of even a simple land development project. Countless hours of planning, evaluation, drafting, reviewing, calculation, and design effort go into each project. It is critically important that the land development engineer be cognizant of the myriad layers of governing regulations, agency review, scrutiny, and overall red tape that will be brought to bear on the project once it is designed. The regulatory approval process can often be the place where a client's great, exciting project ultimately meets an untimely death, if not planned for (in terms of schedule and cost) and diligently, tactfully pursued. Every design engineer should work with the client to develop a regulatory permitting strategy that takes into account all the various regulations and layers of jurisdictional oversight related to the project. This permit strategy should be incorporated into the project schedule to set reasonable time expectations and to identify potential roadblocks to commencing project construction. This may also facilitate the identification of ways to fast-track or expedite the project approval process, which is often a primary goal of many developers.

PRELIMINARY ENGINEERING STUDY DELIVERABLES

At the conclusion of the preliminary engineering effort, the finalized work product typically consists of a set of preliminary drawings, a design checklist, outline specifications and product data, preliminary reports, preliminary construction cost estimates, and value engineering recommendations.

Preliminary Engineering Checklist

Checklists and reports are often prepared during the site analysis, site selection, and feasibility stage of the design process. It is good practice to update and/or prepare new checklists and reports as part of the preliminary engineering process in order to document the design progression—in particular, any noteworthy changes to the development program. An example of a preliminary engineering checklist is provided in Figure 19.26.

Waiver Preparation. During the preliminary engineering stage of the design process, it may become apparent that waivers and/or modifications to local design standards and zoning ordinances might be required. Obtaining waivers or modifications can be critical in meeting the objectives of the proposed development program, to facilitate the eventual construction efforts, or to speed up the design review process. Unique or nonstandard construction details should be preliminarily prepared and analyzed during this stage of the design process.

Green Building Design and Sustainable Site Evaluation. Green building and sustainable site design concepts implemented as part of the project should be reviewed, evaluated, and refined at this stage of the design process with the entire design team and client. From a land development consulting perspective, this step includes a review of the individual green building metrics—in particular, those related to sustainable site development—and an evaluation of whether the site components and design are evolving in a manner conducive to meeting the established project goals. With reference to USGBC's LEED-NC Sustainable Sites category referenced throughout this text, the preliminary engineering evaluation should look at all of the site credits and reevaluate the design elements based on the following considerations:

- Prerequisite: Development of a Construction Activity Pollution Prevention Plan or E&S Plan commences during the schematic design phase.
- Credits 1–3: review and confirm compliance as required.
  - Credit 1, Site Location and Credit 3 Brownfield Redevelopment are a function of the initial site selection and should be confirmed and documented if applicable. If a brownfield site, any remediation and cleanup efforts should be incorporated into the project and permit schedule at this time (see Chapter 17 for additional details).
  - Credit 2, Development Density and Community Connectivity should be reviewed in terms of both compliance paths—site and community FAR of 1.377 or proximity (½ mile) to both a residential community of density 10 dwelling units per acre (du/ac) and 10 basic services that are pedestrian accessible. Regardless of the chosen compliance path, the specific metrics should be verified or checked; specifically, if the second compliance path is chosen, pedestrian facilities between the site and the basic services should be reviewed and preliminary designs developed where needed.
- Credits 4.1–4.4: The Alternative Transportation credits require a complete evaluation of the site parking plan in order to determine a comprehensive approach to meeting these credits in keeping with the project green building goals as well as the owner requirements for parking accommodations. A parking master plan is recommended in order to organize and account for the various combinations of preferred parking, required handicap parking, and other facilities such as bike racks or fueling stations. This master plan should be developed concurrently with any Transportation Demand Management (TDM) strategy that might be warranted as a result of proffers or as a component of the development program in general.
  - Credit 4.1, Public Transportation Access: This credit is predominantly a function of the site selection/location—the site is either within a ½ mile of mass transit or ¼ mile of two bus lines or it isn't; however, if this credit is pursued, the requisite maps and documentation should be prepared at this stage to ensure a thorough understanding of the transit options/routes/stops and that pedestrian routes exist between the site and the qualifying facilities. If

Checklist
For
Preliminary Engineering Study

Date: ____________

Prepared by: ____________

A. Basic Project Information

1.0 Project Name: ____________

2.0 Project Location: ____________

3.0 Client: ____________

4.0 Project Manager: ____________

5.0 Lead Engineer: ____________

6.0 Planner / Other Team Members: ____________

	Yes	No	N/A	Comments
7.0 Has Project Manager visited site? If so, give date(s): ______	______	______	______	
8.0 Has Lead Engineer visited site? If so, give date(s): ______	______	______	______	
9.0 Has Planner and/or Other Team Member(s) visited site? If so, give date(s): ______	______	______	______	
B. Street Design / Site Layout				
1.0 Has the horizontal configuration of the roadways been checked for geometric accuracy?	______	______	______	
2.0 Are the pavements widths correct?	______	______	______	
3.0 Has sight distance been verified both vertically and horizontally?	______	______	______	
4.0 Are sidewalks and/or trails shown in accordance with the requirements?	______	______	______	
5.0 Have the lots and/or land divisions been computed and checked for geometric accuracy?	______	______	______	
6.0 Are all setbacks and building restriction lines shown?	______	______	______	
7.0 Are all existing on-site and off-site easements shown?	______	______	______	
8.0 Are proposed easements shown (approximate widths and locations)?	______	______	______	
9.0 Are off-site easements required for the project?	______	______	______	
C. Storm Drainage				
1.0 Have the horizontal placement and sizing of storm sewer and storm structures been performed?	______	______	______	
2.0 Has select profiling been performed to determine possible vertical conflicts between utilities?	______	______	______	
3.0 Have all existing storm drainage outfalls been checked for adequacy?	______	______	______	

FIGURE 19.26 Example of a preliminary engineering checklist.

D. Stormwater Management

1.0 Has storm water detention facility(s) been sized to achieve the required quality and release rate? ______ ______ ______

2.0 Has the spillway capacity been determined? ______ ______ ______

3.0 Has a preliminary dam break analysis been performed? ______ ______ ______

E. Floodplain

1.0 Is there a floodplain present? ______ ______ ______

2.0 If so, has it been modeled using field-run topography? ______ ______ ______

F. Grading / Earthwork

1.0 Has a grading study been performed? ______ ______ ______

2.0 Has an earthwork analysis been performed? ______ ______ ______

3.0 Have the soils been evaluated? ______ ______ ______

G. Wastewater Collection / Wastewater Treatment

1.0 Is public sanitary sewer available to the proposed project? ______ ______ ______

2.0 If so, is there capacity in downstream sewer and treatment facilities for the proposed improvements? ______ ______ ______

3.0 Have the horizontal placement and sizing of sewer been determined? ______ ______ ______

4.0 Has select profiling been performed to determine possible vertical conflicts between utilities? ______ ______ ______

5.0 If public sanitary sewer is not available, what method will be used for wastewater treatment? ______ ______ ______

H. Water Distribution / Water Treatment

1.0 Is public water service available to the proposed project? ______ ______ ______

2.0 If so, is there adequate pressure in the existing system and are the fire flow requirements met? ______ ______ ______

3.0 If public water is not available, what method will be used for water supply? ______ ______ ______

I. Erosion and Sediment Control

1.0 Has a general erosion and sediment control program been determined for this project? ______ ______ ______

J. Cost Estimates

1.0 Have preliminary costs been determined for the proposed improvements? If so, list them. ______ ______ ______

2.0 Have fees associated with the development program been determined? If so, list them. ______ ______ ______

FIGURE 19.26 *(Continued)*

K. Miscellaneous				
1.0 Are any waivers and/or modifications to local design standards and zoning ordinances required?	______	______	______	
2.0 Are there any wetlands and/or other environmental constraints associated with this site?	______	______	______	
3.0 Is gas service available to this project?	______	______	______	
4.0 Is electric service available to this project?	______	______	______	
5.0 Is telephone service available to this project?	______	______	______	
6.0 Is cable television service available to this project?	______	______	______	

Figure 19.26 (*Continued*)

pedestrian improvements are required, they should be incorporated into the preliminary engineering design.

□ Credit 4.2, Bicycle Storage and Changing Rooms: These should be provided in close proximity to a building entrance. Computations should be performed to determine the number of bike stalls/racks required, and they should be located on-site in the preliminary plan. Coordination with the architect and/or MEP is important in commercial applications in order to ensure the shower provision is also met and bike and shower facilities are located accordingly.

□ Credit 4.3, Low Emitting and Alternative Fueled Vehicles: There are three compliance paths for this credit; options 1 and 2 relate to the provision of and preferred parking for Low-E and alternative vehicles, while option 3 requires alternative fuel refueling stations to be provided. In terms of the preliminary engineering plan, preferred parking should be accommodated and denoted in the overall parking scheme; a detail for signage needs to be developed as part of the final engineering effort. If refueling stations are the preferred compliance path, appropriate siting/location of the facilities should take place, and the engineer should begin to understand any utility, screening, or special design requirements related to this facility.

□ Credit 4.4, Parking Capacity: This is a critical credit to assess during the preliminary engineering phase, as parking counts are often set or committed to during the rezoning/entitlement process. This credit emphasizes meeting but not exceeding local zoning ordinance parking requirements, providing preferred parking for ride-sharing scenarios, and developing transportation demand management (TDM) programs in order to minimize on-site parking requirements and encourage alternative forms of transportation. Preferred parking spaces for car pools or van pools should be designated on the parking master plan and a signage detail developed.

■ Credits 5.1–5.2, Site Development: This includes evaluation of design measures to protect and restore natural habitat and to maximize open space on the site. As discussed in Chapter 15, consideration of this credit is important during the schematic design phase as limits of clearing grade begin to take shape. These limits should be carefully considered, refined, and modified during the course of preliminary engineering to accommodate infrastructure needs (including construction staging and installation requirements) while balancing the target open-space goals for the site.

■ Credits 6.1–6.2, Stormwater Design: This includes reviewing provisions to reduce quantity of site runoff and inclusion of design strategies to provide water quality treatment of stormwater runoff. As indicated in the preceding discussion of preliminary engineering of stormwater management facilities, the first step is determining the applicable requirements. It should be noted that often the local jurisdictional SWM requirements differ from the specific metrics of Credits 6.1 and 6.2, in which case the engineer must determine the goals of the SWM program in consultation with the client and the rest of the design team. Once a clear SWM goal is determined, facilities can be considered and preliminarily designed to meet the requisite criteria (see Chapter 22).

■ Credits 7.1–7.2, Heat Island Effects: This includes review of design provisions to reduce rooftop and non-rooftop heat island effects, most often resulting from the creation of new paved surfaces. Implementation of design features such as highly reflective (white) roofing or green roofs and incorporation of shade features, such as shade trees in parking areas, highly reflective or open grid paving, and/or covered parking, are tactics for reducing the heat island effect. During preliminary engineering it is appropriate to start looking at the material selection for site-impervious features such as sidewalks, trails, and plazas as well as developing a landscape or streetscape concept to address provision of shade. Although these details are more typical of final engineering design, coordination of this effort with the design team is important, as many credits are purposely linked to produce synergy in design—for instance, a green roof most definitely would help achieve Credit 7.1 but might also help to achieve the stormwater credits (6.1 and 6.2) and open-space credits (5.1 and 5.2), depending on the site location and the development program as a whole, not to mention the internal building benefits that would be examined under the Energy and Atmosphere category. It is important for the design team to work collaboratively at this point to optimize site and building features from both a functional and a cost perspective. Understanding the rating system, the project goals, and the owner's requirements are key to developing a sustainable site plan.

- Credit 8, Light Pollution Reduction: This includes review of proposed site lighting to ensure that lighting is maintained at a minimal level to the extent possible and light sources are shielded to minimize night glow from the site. As indicated in Chapter 26, a lighting consultant is likely required in order to provide the most efficient lighting system in terms of meeting safety and comfort standards while minimizing light pollution. That consultant should be brought onto the design team, if not already included, and should begin to lay out a lighting scheme and research fixtures in concert with refinement of the preliminary plan.

- Water Efficiency Credit 1 (Water Efficient Landscaping) and Credit 2 (Innovative Wastewater Treatment Technologies) should also be considered and reviewed during the schematic design. If required, an irrigation consultant should be brought onto the team. The irrigation system design should be developed concurrently with the landscape and stormwater management plans, especially if water reuse is a desirable strategy. If on-site wastewater treatment is a site requirement as determined during the feasibility study and further refined during the course of preliminary engineering, treatment strategies should be examined and refined with respect to this credit if possible.

If the targeted green building goals—specifically, the site components—are not being attained, an assessment of the specific site metrics as outlined here should be performed to determine other measures or design principles that should be incorporated into the design during the course of final engineering. Changes to the design program are bound to occur; savvy land development consultants should be aware of and attentive to the various green building strategies employed on the project as a whole so that they can adapt, refine, and innovate throughout the design process to optimize the site's potential, developing strategies that are buildable and sustainable.

VALUE ENGINEERING

An important part of preliminary engineering is determining the most economical approach to design and construction without significantly altering the design program. The process of economizing the design program is termed *value engineering* and should be accomplished before final engineering.

The main purpose of value engineering is to identify cost-saving opportunities to the developer/builder. This effort may include members of the project team, such as the architect and planner, public agency reviewers, the project attorney, the construction manager, and the developer/builder.

During a typical value engineering review, it might become apparent that the site elevation should be raised or lowered to balance the earth materials, based on the preliminary grading and earthwork calculations. Reconfiguring lots may reduce street lengths and utility requirements. Perhaps regrading or adding retaining walls might preserve more open space and trees.

Performing a value engineering study during the preliminary engineering phase allows design and cost issues to be reviewed and potential options to be identified prior to final design. This provides an opportunity to make design adjustments with less impact to the schedule and the effort required to complete the design.

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PART V

FINAL DESIGN

STEP 5: FINAL DESIGN

Predominantly an engineering effort, the final design phase is where fine-tuning and detailing of all site components occurs. Each infrastructure system—roads, grading and drainage, utilities (gravity, pressure, and dry), vegetative or natural open space—must be accounted for, coordinated, and designed with respect to the requirements of the specific review agency. Sufficient information in the form of drawings, computations, details, narratives, and/or specifications must be provided such that regulatory agencies can review and approve final construction documents and contractors can implement the intended design.

Plans developed during this phase of the design are used for permitting, construction, and final cost estimating purposes; thus, it is important to maintain close and constant communication with other design team members—architects; mechanical, electrical, plumbing engineers (MEPs); landscape architects; and private utility contractors, to name a few—in order to accurately and efficiently coordinate plan interfaces. Such interfaces occur between the building and the site systems as well as between private property and public rights-of-way (ROW). The site-civil engineer is the intermediary connecting the building to public property and, consequently, is responsible for ensuring design consensus at these transition points. Key design elements such as location, size, invert, material preference, maintenance responsibility, and easement requirements must be reconciled among the various involved parties in order to package all plans together in a single, coherent bid and/or permit document.

Traditionally, the plan interfaces or transition points represented a strict design divide: architects and/or MEPs designed all systems within 5 to 10 feet of the building, public utilities were generally stubbed out to ROW lines, and the site-civil engineer merely had to design the connections. Today, these design divides are dissipating as building and site systems become more integrated, mostly as a component of sustainable or green design efforts. For instance, stormwater collection and treatment systems that support landscape irrigation efforts and/or building nonpotable water needs represent a commingling of site stormwater design with building plumbing design. This type of system interaction is not uncommon for projects pursuing the higher levels of green building certification, and it extends beyond just stormwater and plumbing systems to include nearly every infrastructure system.

Final design is the phase where the project goals, intents, and any sustainable or innovative design strategies, planned and envisioned in earlier phases of the process, are fully integrated and detailed in the construction documents. The collaborative effort required to detail, specify, and incorporate such strategies is extensive; however, efforts in this phase will improve plan clarity and facilitate smooth construction of the project.

CHAPTER 20

STREET DESIGN

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INTRODUCTION

While the design of streets should follow the standards and guidance established by the well-known transportation agencies and organizations, this chapter introduces additional guidance for the design of streets in a lower-speed environment typically associated with land development projects. Traffic-calming measures and bicycle facilities are a few growing concepts that designers need to consider and introduce into their land development street designs with the intent of creating a safer roadway environment.

Most of the design guidance for high-speed, high-volume highways has been established by organizations such as American Association of State Highway and Transportation Officials (AASHTO), Institute of Transportation Engineers (ITE), and Federal Highway Administration (FHWA). Design guidance for low-speed roads is typically established by local municipal or state agencies by modifying the criteria for highways. However, the popular AASHTO design manual *A Policy on Geometric Design of Highways and Streets* has incorporated discussions and provided design guidance regarding local roads and streets in both urban and rural settings. Many local agencies have adopted the AASHTO manual entirely or with modifications to reflect regional philosophies and conditions. AASHTO guidance represents the consensus of state transportation agencies, the FHWA, representatives of the American Public Works Association, the National Association of County Engineers, and others. They provide a consistent basis for street design with appropriate variations for climates, terrain, and economic factors.

The FHWA publishes the *Manual on Uniform Traffic Control Devices* (MUTCD). This manual has been officially adopted by most states and has become an important legal document because it ensures that signs, pavement markings, traffic signals, and other traffic control devices are uniformly and consistently applied. Local jurisdictions, in most instances, are required by state law to conform to the MUTCD. Use of this standard applies to both the selections of appropriate traffic control devices and design and application of pavement markings and signs.

High-speed, high-volume highway design is governed mostly by vehicle and driver characteristics. Local street design is governed by the same criteria but to a lesser degree. More emphasis is placed on pedestrian safety, local service, land accessibility, and the preference by residents for a pleasant environment.

The safety of pedestrians and bicyclists is a major consideration in the planning and design of roadways. This is particularly important in urban environments where their interaction with vehicular traffic is high. Both AASHTO and ITE have published manuals that provide guidance for the development of safe pedestrian and bicycle facilities. In addition, the Americans with Disabilities Act Accessibility Guidelines (ADAAG) must be followed during the design process, especially in public street applications.

In many localities the actual construction and the cost of construction of the street network of a development project are the responsibility of the developer. Once the streets are constructed, they are then accepted as part of the local or state street network system, and the costs of repair and maintenance become the responsibility of public agencies. Maintenance costs, in most cases, are funded through local and state taxes. Higher-order roads, on the other hand, are typically constructed with state and federal funds and maintained with state funds.

It is imperative for the streets to be designed and built according to the governing criteria. Failure to do so often results in additional design and construction costs in order to have the street accepted into the state or local system. Nonstandard design may also cloud liability in accident cases. Some developers choose to provide private streets. The cost burden for repair and maintenance is then the responsibility of the collective private owners.

FUNCTIONAL CLASSIFICATION OF STREETS

Several different classification systems exist for grouping highways and streets. These systems are used by different agencies and other interest groups to establish a common base according to a particular interest, function, or operation of the road. The various systems include grouping for administrative purposes to identify the levels of government responsible for construction and maintenance, grouping according to eligibility for various sources of funding, grouping by traffic volumes for traffic operations, grouping according to geometric design for setting design standards and priorities, and grouping by character of service provided by the road as a functional classification. Geometric design category is of interest to design engineers, and the lowest category—residential, commercial, or industrial access—is one of particular interest to land planners for development projects.

The AASHTO handbook *A Policy on Geometric Design of Highways and Streets 2004* includes a detailed discussion of functional highway systems. AASHTO describes a typical trip as including the following six stages of travel movement or service to facilitate vehicular movement: main movement, transition, distribution, collection, access, and termination. The roadway functions and traffic volumes are directly related to the movement hierarchy served. Figure 20.1 illustrates the hierarchy of movement and depicts the use of roadways within a typical trip. In many land development projects, the majority of the planning and design focuses on the roads pertaining to the latter parts of the travel movement—terminal access, collection, and, occasionally, distribution.

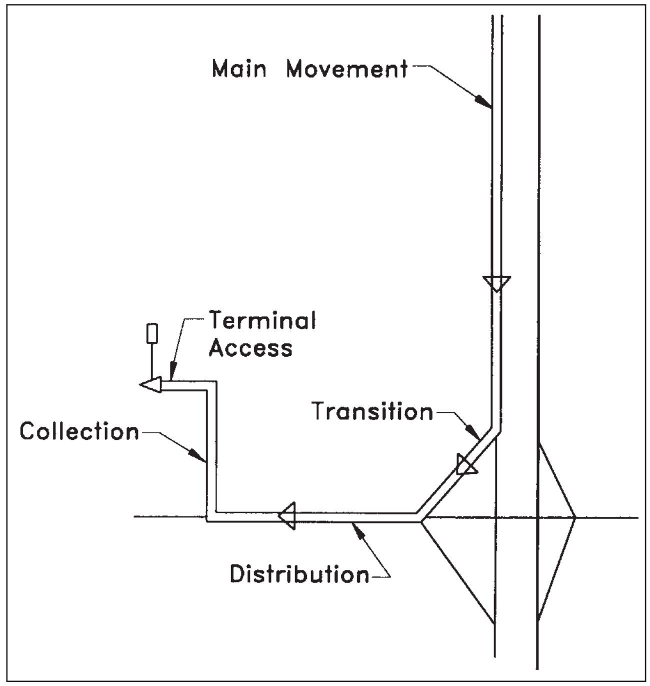

FIGURE 20.1 Hierarchy of movement. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

The highway and street network provides travel mobility and access to property. Mobility is an all-encompassing description that includes riding comfort, absence of speed changes, operation speed, and travel time. At one end of the functional category are the high-access/low-mobility local roads and streets. The other extreme is the high-mobility/low-access arterial highways such as freeways. Between these two extremes are the collection and distribution roads that link the two functional extremes.

Functional classification is divided into rural and urban systems, which possess different vehicle and traffic characteristics. The systems differ in travel patterns, the density of the streets and highways within the network, and the type of land served by the network. As might be inferred, the population density sets the distinction. Comparatively dense areas, as designated by state or local officials, with populations of 5000 or more people, are considered urban. Population is used to further divide this category into two subcategories: *urbanized areas,* those with populations of 50,000 and over, and *small urban* areas defined by a population between 5000 and 50,000. As shown in the AASHTO handbook, the urban functional system divides streets into principal arterial, minor arterial, collector, and local functions.

The urban principal arterials provide service to major centers of activity and are the corridors that accommodate the highest traffic volume. A high proportion of the urban area travel occurs on the principal arterial system. In the urbanized areas it is these streets that provide linkage to the rural arterial roadways. The principal arterial system is composed of several types of roadways with full control of access, such as interstate highways and other freeways, and other principal arterial streets with partial or no control of access. The spacing of these principal arterials varies with the density of the urban areas.

Next in the hierarchy of the urban functional system is the minor arterial street system. These distributor streets provide greater access to adjoining land than that afforded by the principal arterial system. Traffic movement, as compared to the principal arterial system, is greatly impeded. Minor arterial streets provide travel between communities and possible connections to rural collector roads. Typically, such roads provide the boundaries of identifiable neighborhoods. Their spacing relates to the density of the developed area. Spacing ranges from ½ mile to 3 miles. In fully developed areas the spacing normally does not exceed 1 mile.

The urban collector street system provides for land access and traffic flow in all land use areas. These streets link the local street system with the principal and minor arterial

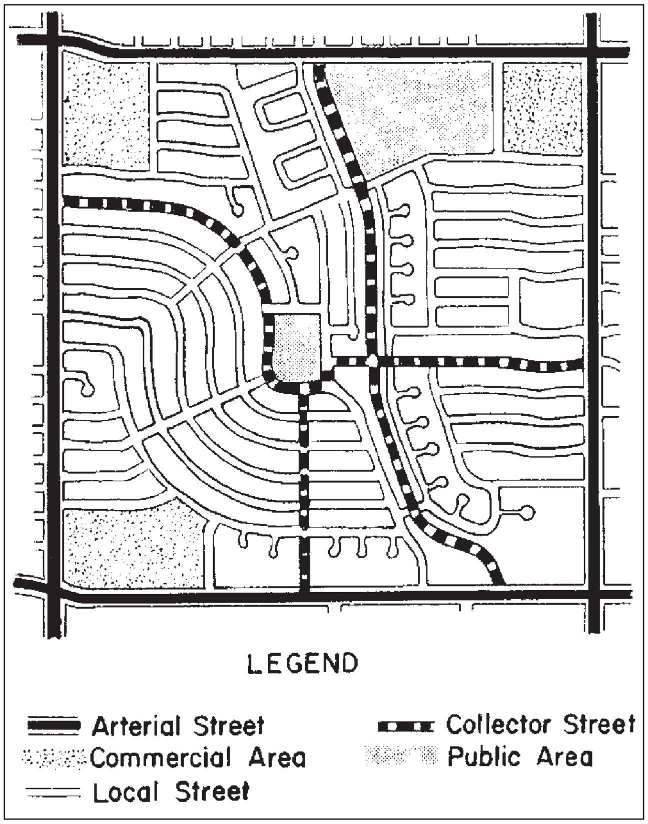

Figure 20.2 Suburban street network. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

street systems. Collector streets through predominantly residential areas serve as the main access to the development from the arterial or another collector. The residential collector street has average daily traffic (ADT) counts of 1000 to 3000 vehicles per day (VPD). Single-family dwelling units may have direct access on these roads where traffic volumes are on the lower end of this range. However, as traffic volumes increase, perhaps due to the length of the collector or the land use it serves, direct access becomes less desirable and left-turn movements are often restricted. An option to consider is to design the development project such that the collector accesses multifamily residential dwelling units with off-street parking such as town houses and condominiums, schools, and other public facilities. As the collector street traffic volumes approach 3000 VPD, access to single-family units becomes undesirable; however, access to small public and local commercial/retail facilities would still be considered appropriate.

Lowest in the hierarchy is the urban local street system. The main function of the local street is access to the land adjoining the roadway and linkage to streets mentioned previously that are higher in the order within the functional system. Whereas collector streets are the main routes that provide access to the development, local streets provide access to the properties within the development. In residential areas, the volume of local streets is usually less than 1000 VPD.

Figure 20.2 schematically shows the functional classification of streets and the interconnection of the street hierarchy. A summary of the characteristics of the AASHTO classification appears in Table 20.1.

Other organizations besides AASHTO have developed a functional system that relates to residential and suburban settings. The National Association of Home Builders, the American Society of Civil Engineers, and the Urban Land Institute formed a task force to assimilate data and publish a manual to aid in appropriate local street design. This manual, titled *Residential Streets* (3rd ed., 2001), defines the street categories as arterial, collector, and local access. Accordingly, residential streets are included in all groups except arterial. The definitions of arterial and collector streets correlates to the AASHTO definitions. The access street carries no through traffic. It serves only to access the lots located along it. Streets such as cul-de-sacs, dead-end streets, loop roads, courts, and alleys fall into this category.

Ultimately for land development projects, street classification falls into the domain of the local controlling body. Description and definition of the street categories are usually found in local subdivision ordinances and standards. In all likelihood, the categories will be defined according to function and in part by anticipated traffic volumes. Regardless of the basis for grouping, categories should follow a pattern similar to those outlined here.

TABLE 20.1 Summary of Characteristics of the Functional System

Street Classification	Service Area	Relative Volume	LOS*/Operating Speed	Access Control
Principle arterial	Through movements; major activity centers	High	High	Full to Partial
Minor arterial	Lesser activity centers	High to Medium	High to Moderate	Some limitation
Collector	Regional and some local land access	Medium to Low	Moderate to Low	None
Local	Neighborhood land access	Low	Low	None

*Level of service—a qualitative measure of the operating conditions.

Placing priority on function when designing local access streets requires that the designer consider many related factors apart from average daily traffic. Land development projects are only pieces in the regional development scheme. Design of streets within a project should, therefore, conform to the overall street system for the entire neighborhood. Such factors as economy, efficiency, safety, and viability lead to functionally well-designed streets.

DESIGN CONSIDERATIONS

Traffic Volumes

The design capacity—that is, the traffic volume that can be supported by a street—depends on factors such as width, horizontal curvature, vertical curvature, longitudinal street grades, superelevation, roadside obstructions, intersections, and traffic control measures. These criteria are usually specified as minimums for residential access streets and are determined by the need for fire access and whether on-street parking is permitted. For collectors and arterials, it is necessary to design the street for the traffic volumes it is expected to maintain at some future date. These traffic volumes are determined during the initial traffic studies conducted during the preliminary design phases. Traffic data, such as average daily traffic and peak-hour traffic volumes, is essential to establish the geometric design features of the street. For additional discussion on traffic data collection and analysis, see Chapter 5.

Driver Characteristics

The characteristics of vehicles and drivers using the roadway directly affect the geometric design. Driver behavior and response to various situations fluctuates based on conditions. Behavior and response for the same situation and condition vary for the same driver at different times due to physical condition and mental attitudes. Likewise, the performance of vehicles varies due to size, weight, power, mechanical condition, and the driver. Road design must account for some minimum standard of driver behavior and vehicle performance.

Individuals vary, and, therefore, as an added measure of safety designers must account for below-average driver characteristics, with the presumption that a majority of drivers will have these minimum threshold characteristics. Drivers' fundamental characteristics include perception, identification, emotion, and volition (PIEV).

Perception includes seeing and observing objects. Identification consists of comprehending an encountered object and its surrounding elements. Emotion involves judgment and the process of decision making, leading to responsive actions. Volition or reaction is the driver's will to react to or execute the actions decided during the emotion process. The total time elapsed through the PIEV process is referred to as the *PIEV time* or, more commonly, the *perception-reaction time*.

PIEV time varies with the complexity of individual situations. Factors such as the use of drugs and alcohol, age, fatigue, and physical impairments cause increases in PIEV time. Studies conducted in laboratory situations determined PIEV time as falling in a range from 0.5 seconds to 7.0 seconds. Highway agencies typically use PIEV times of 2.5 seconds for stopping distance and 2.0 seconds for determination of adequate sight distance at intersections. The latter is shortened because the driver anticipates a possible reaction at intersections. Similarly, familiarity with common signs and traffic markings reduce PIEV time because perception identification and emotion occur almost instantaneously.

Vehicle Characteristics

Roads are designed to accommodate the characteristics of the vehicles using them. There is a wider range of vehicle types using arterial roads as compared to vehicle types using local streets. In addition, the frequency of occurrence of specific vehicle types is higher on arterial roads. For example, a large truck (e.g., moving van) is only occasionally found on residential streets, but large trucks are common on arterial streets. Therefore, for economic reasons, streets higher in the functional hierarchy must be geometrically and structurally designed to accommodate larger vehicles. In comparison, the design requirements for local streets may not have to be as stringent. For example, lanes for local streets may not be as wide as for arterials, curve radii may be shorter, and grades steeper. Local requirements for pavement structure and operating room for fire apparatus often provide more than adequate design for other, similar vehicles.

The largest vehicle type that is most likely to use the roadway with regular frequency is selected as the design vehicle. The physical and operating characteristics of the design vehicle are then used to establish critical geometric and structural design features of the road. Local streets, like any roadway, must accommodate the predominant vehicles using this type of functional street. The predominant vehicle on local streets is the private passenger car, including small-, medium-, and large-size cars, vans, and pickup trucks. In high-density developments (e.g., town houses or condominiums), typically the travel way is not publicly owned and maintained. Consequently, design criteria for minimum widths and radius of curvature are even less than those prescribed for local public streets. However, the design engineer must consider the use of these streets by emergency vehicles, moving vans, refuse trucks, school buses, and other large vehicles. Typical dimensions and minimum turning paths for a variety of these design vehicle types can be found in Chapter 2 of the AASHTO design manual, "A Policy on Geometric Design of Highways and Streets."

Circulation and Access

Traffic circulation and ease of access often determine a land development's consumer appeal. In purely residential developments, the recommended practice is to discourage outside-generated through traffic, by limiting the number of access points to the arterials or collectors or by designing the internal streets in short, narrow, curvilinear, discontinuous patterns. Although multiple access points might encourage through traffic, they do provide for less congestion because of more dispersion of the traffic from within the residential development. In mixed-use developments and commercial/retail projects, the access and circulation pattern is more complex. Circulation and access are important to facilitate the traffic flow through the commercial and retail sections. However, the commercial and retail traffic should not be directed through residential areas. Proper planning of the development necessitates that the residential section be located apart from the business areas to reduce the high traffic volume's impact. As previously mentioned, through traffic can be discouraged by street geometry and configuration, but this strategy is most effective if the minor arterials have adequate capacity and provide a good level of service.

Street circulation is site oriented to a degree. Where and how the streets are oriented depend on the interrelationships of various aspects such as lot layout, topography, noise levels, accident potential, and other factors. To accommodate access and circulation demands, street networks have evolved into grid and/or curvilinear patterns that fit certain situations and lend themselves to particular solutions.

Grid Patterns. The *grid pattern* is a series of parallel streets intersecting at right angles, creating rectangular blocks. The grid is best suited for use in high-density areas with widely distributed traffic flows. Grid systems provide easily recognizable orientation for users. Their simplicity in providing access is a definite advantage. The grid system simplifies surveying and maximizes the number of houses fronting on a street.

Grid street systems dictate the topography by forcing a specific grading design in order to obtain buildable lots. Therefore, they are best suited for generally flat areas. Imposing a grid system on rolling terrain in most cases requires extensive grading. Other drawbacks to this type of system are the monotony of the layout and the lack of differentiation of function between individual streets within the system. The system also invites through traffic. These drawbacks can be overcome with imagination and by variations from the typical grid. Figure 20.3 illustrates the simple grid pattern and modifications such as using secondary loop roads to provide a more attractive environment while discouraging nonlocal through traffic.

Curvilinear Patterns. Many medium to large projects develop a curvilinear type of street pattern. Such a pattern discourages cut-through traffic, optimizes land use, and minimizes cut and fill grading operations during construction by taking advantage of the existing topography for streets and, also, lot orientations and configurations. Such patterns create a sense of neighborhood on a small scale by collecting the lots into small groupings through the use of smaller elements of street patterns such as cul-de-sacs, loop courts, and short streets (see Figure 20.4). Such a pattern's drawback is the confusion that may result when attempting to traverse the area. Extensive curvilinear patterns are not recommended for commercial and industrial developments.

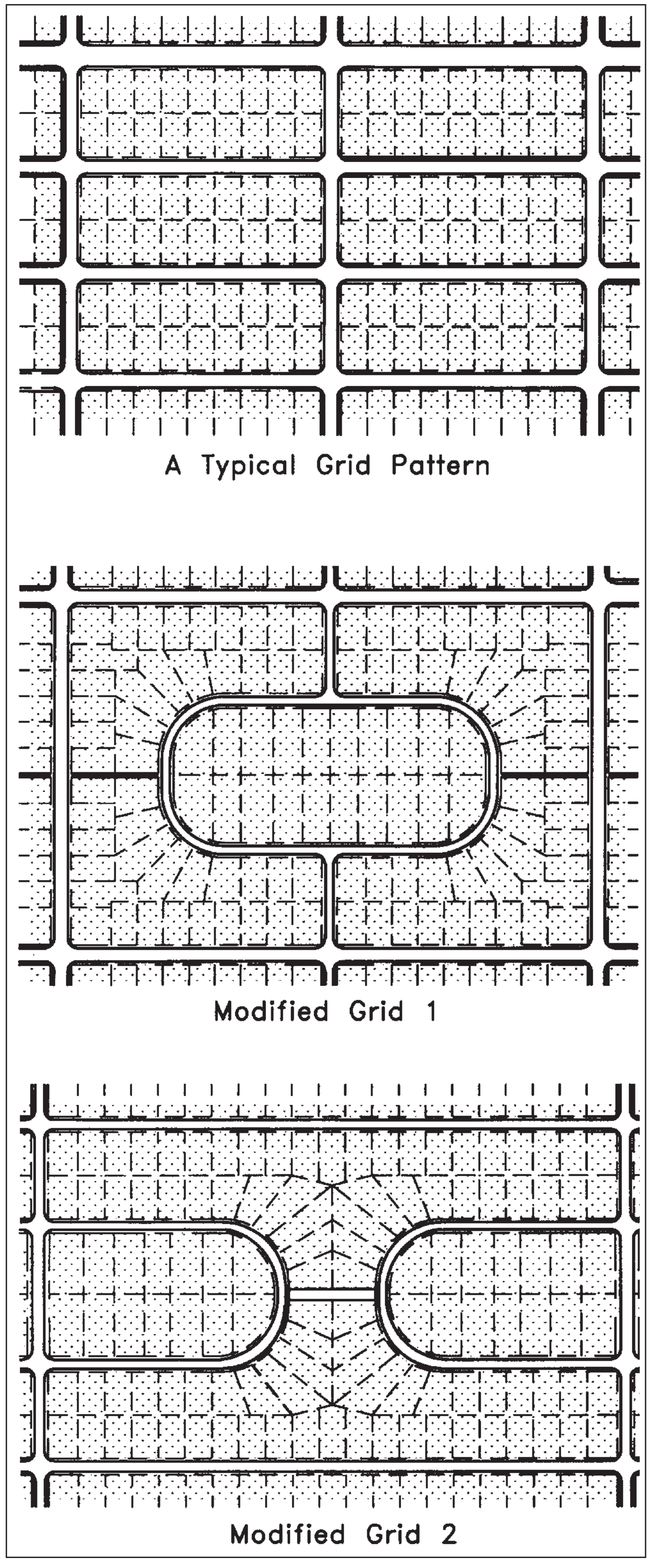

Figure 20.3 Grid pattern and variations. (DeChiara, J. and L. Koppelman. 1984. *Time Saving Standards for Site Planning.* New York: McGraw-Hill. Reproduced with permission of McGraw-Hill)

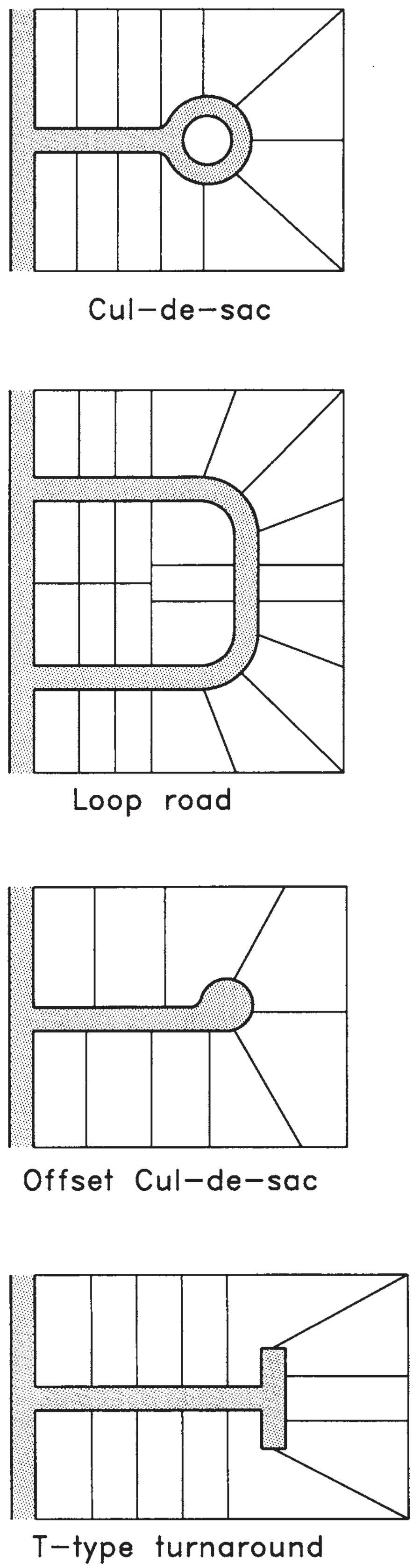

FIGURE 20.4 Smaller elements of street patterns. (DeChiara, J. and L. Koppelman. 1984. *Time Saving Standards for Site Planning.* New York: McGraw-Hill. Reproduced with permission of McGraw-Hill)

Circulation and access may be considered from two different scales as they apply to the development's proposed public street system, and as they apply to a specific land parcel. In both situations, circulation and access are constrained by the existing street network, adjacent property, and the intended type of land use for the proposed development.

Frequently, providing for adequate circulation and access requires improvements to existing infrastructure elements beyond the limits of the site, and these are often financed by the developer. Turn lanes added to the existing street or signalization of an intersection to improve capacity and safety are examples of such required off-site improvements. Necessary considerations for circulation and access include the following:

- Will the intersection of the proposed street adversely impact existing intersections?
- Is there adequate horizontal and vertical sight distance at the new access point?
- Will turn lanes be required?
- Will any intersections require signal control?
- Will any streets within the development be required to terminate at a particular point on the boundary to allow for access to adjacent properties for future development?

Considerations for access to a particular parcel such as entrances (driveways) into commercial/retail sites should address:

- Is the driveway length (i.e., throat length) adequate to allow for vehicle queuing into and out of the parcel?
- Is the driveway entrance too close to other driveway entrances or to an intersection, which causes conflicts in turning movements?
- If there is a median in the driveway, is it visible by the vehicles turning into the entrance?
- Are the profile and cross section of the driveway adequate and compatible with the roadway conditions?

Circulation within the parcel should also be considered:

- Is a loop road or perimeter road appropriate?
- Does the parking area need to be partitioned or somehow sectioned to facilitate traffic flow?
- Are the landscaped islands adequately sized (e.g., radius and widths) and located for visibility and circulation?

Pedestrians

Pedestrian safety is a concern on any roadway where a combination of vehicular traffic and people occur. Pedestrian density substantially increases in the lower classifications of streets in both residential and commercial areas. In residential areas there is an added emphasis on child safety. Not to be overlooked are the safety concerns of pedestrians in parking areas. Parking areas are complex in that the driver, although proceeding slowly, must contend with numerous vehicle and pedestrian movements occurring nearly simultaneously. Pedestrian movements along and randomly crossing travel ways, vehicles entering and exiting parking spaces, as well as the movement and turns of the normal traffic all contribute to parking area hazards.

Planning for the pedestrian is a high priority in the design of roadways at the local level. Pedestrian safety provisions included in roadway planning are sidewalks, crosswalks, curb cuts, and ramps for the physically disabled. Another such provision is special walkways for pedestrian freeway crossings. Traffic control features aid both pedestrian traffic and vehicular traffic.

Sidewalks should provide a continuous path to service areas such as community centers, schools, parks, and shopping areas. Most ordinances require sidewalks on at least one side of the street. In some residential areas the ordinance may require a paved trail in lieu of or in addition to the conventional sidewalk.

Conventional sidewalks typically are adjacent and parallel to streets and travel ways, whereas paved trails meander along natural pedestrian circulation routes. The most obvious indication of a sidewalk or trail deviating from natural

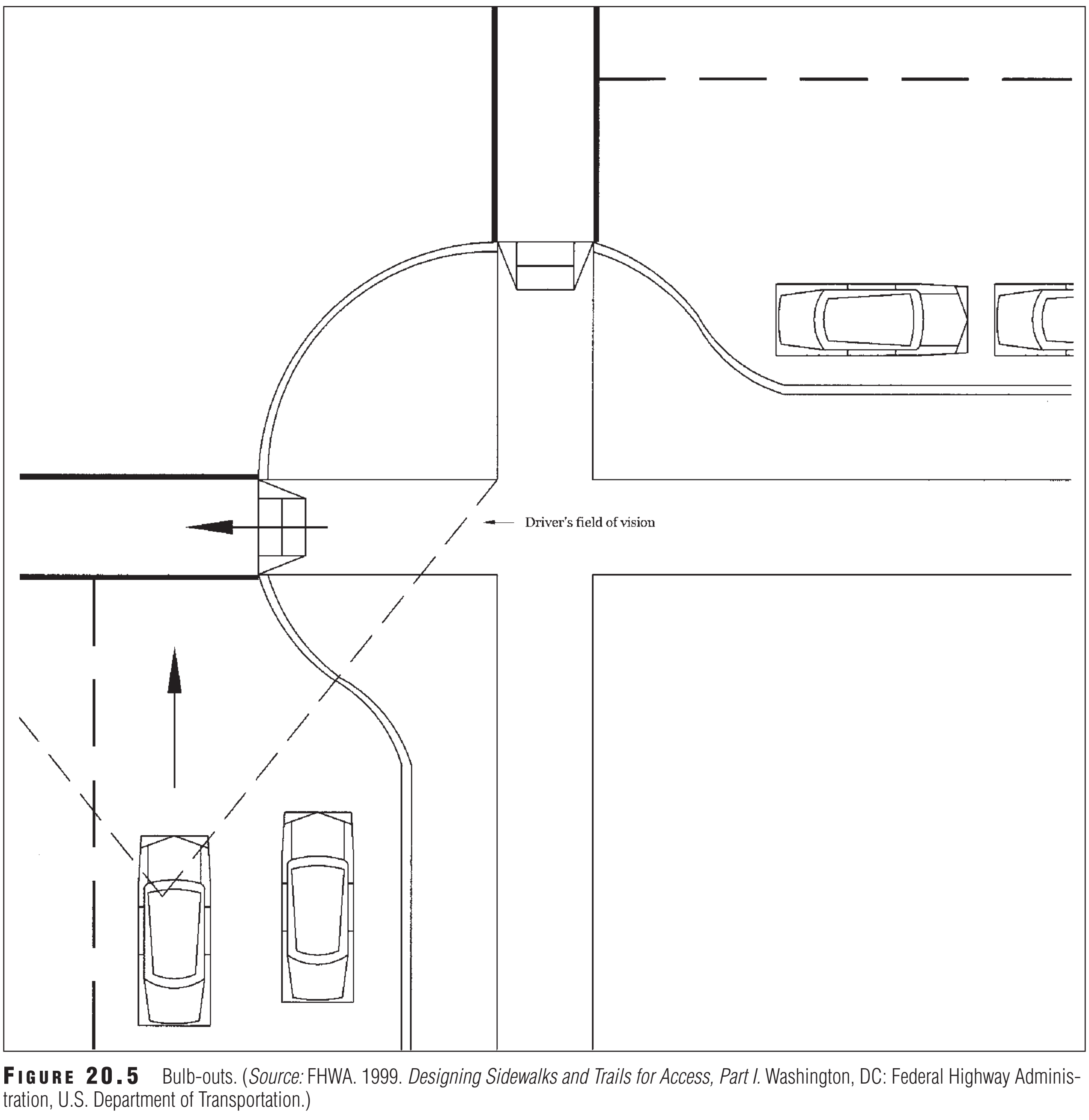

FIGURE 20.5 Bulb-outs. (*Source:* FHWA. 1999. *Designing Sidewalks and Trails for Access, Part I.* Washington, DC: Federal Highway Administration, U.S. Department of Transportation.)

circulation is the worn earthen path. Besides being an eyesore, this may create problems for the private owners whose property is being trespassed. Additional design guidance for pedestrian facilities is included under "Sidewalks and Utility Strips" later in this chapter.

Another provision is the need for landing and staging areas at bus stops. Unfortunately, bus routes through new residential developments are rarely established prior to completion of the development. Providing landings and pedestrian circulation to these locations, when possible, adds to the appeal and safety of the land development project.

One of the most dangerous maneuvers for pedestrians is to cross a wide street at an unsignalized intersection. One option to increase pedestrian safety is to locate bulb-outs at corners, as shown in Figure 20.5. This not only reduces the pedestrian crossing distance but also creates an illusion of a narrower street to drivers, who instinctively reduce their speed. Additional traffic-calming measures are discussed later in this chapter.

Bicyclists

The increase of bicycles as a popular mode of transportation has created the need for the introduction of bicyclist safety measures on streets and highways. Unfortunately, many existing roads were not designed to accommodate an ever-increasing number of bicyclists sharing the road. However, in areas of new construction where a significant number of bicyclists are expected provisions can and should be made by the designer.

Ideally, bicycle routes should be located outside the paved roadway section when sufficient right-of-way is available. This additional space is not always available or may be occupied by sidewalks and utility strips. As a result, bicycle facilities can generally be designed as one or a combination of the following types.

Type I—Off-Street Path. These bikeways should be used on high-volume, high-speed roadways, provided right-of-way space is available. They can be designed wide enough to accommodate both bicyclists and pedestrians. Provisions such as low curbs or planting strips should be considered to separate these two modes of transportation.

Type II—Bicycle Lane. These bikeways are on-street striped routes. They can be located adjacent to curb lines or adjacent to parking lanes. In either case, a narrow, painted buffer should be considered to separate the bicycle lane from the adjacent travel lane. These bikeways can be installed where sufficient street width is available or can be provided without restricting vehicular traffic. Figure 20.6 shows a typical Type II bicycle lane with suggested pavement markings.

Type III—Bicycle Route. The least desirable bikeway of the three is the on-street signed route. This type is to be used where there is insufficient curb-to-curb width to accommodate the striped Type II bicycle lane and in some cases to provide continuity to other Type I and/or Type II bikeways in the area.

Curb-Cut Ramps

Curb-cut ramps are required by the ADAAG at most intersections and all crosswalk locations. According to the ADAAG, curb-cut ramps should be a minimum of 3 feet wide and the slope should not exceed 8.33 percent (1V:12H). A detectable warning surface such as truncated domes must also be provided for 2 feet longitudinally and for the full width of the ramp for individuals with vision impairments. Most states and municipalities provide standards detailing curb ramp dimensions and intersection locations. Issues for consideration in the placement and design of curb-cut ramps include the following:

- Curb-cut ramps should not be provided to cross a "T" intersection unless there is a painted crosswalk or traffic device (stop sign or traffic signal) controlling the major street (the top of the "T").
- Curb-cut ramps should not be located at low points where drainage inlets are located.

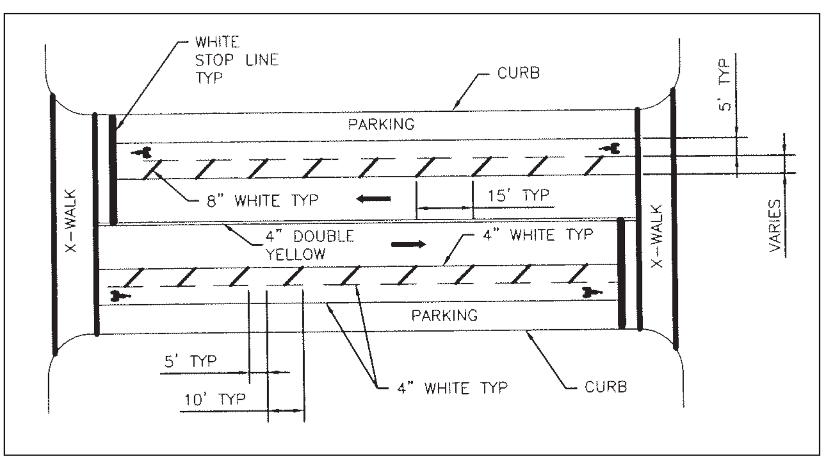

FIGURE 20.6 Type II bicycle lane.

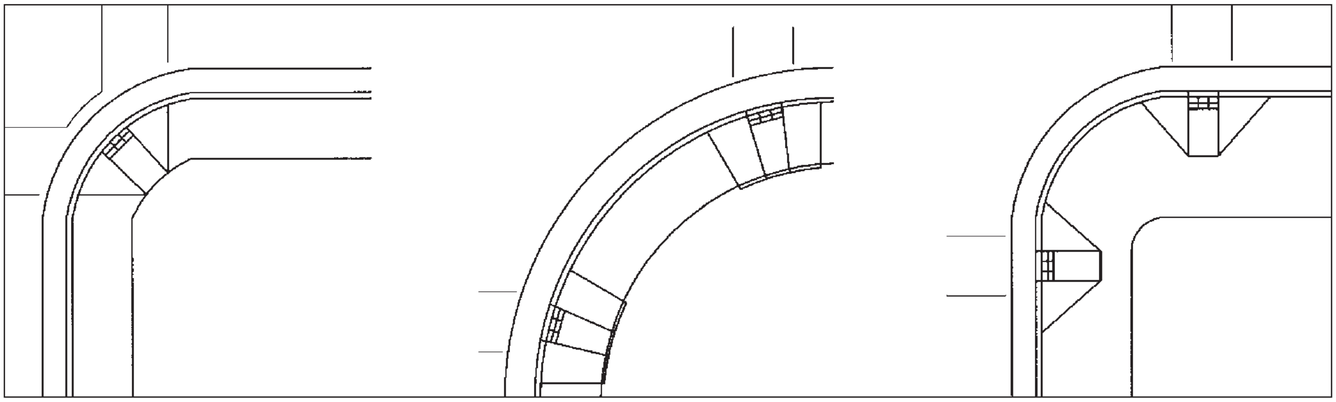

Figure 20.7 Curb-cut ramp types. (*Source:* FHWA. 1999. *Designing Sidewalks and Trails for Access, Part I.* Washington, DC: Federal Highway Administration, U.S. Department of Transportation.

- Curb-cut ramps are to be provided on curbed traffic islands located within the crosswalk areas.
- Curb-cut ramps should be located away from areas where parked cars will obstruct the path.
- Curb-cut ramps should be located at the best pedestrian sight distance locations.

Typical curb-cut ramp types and curb-cut ramp details with recommended dimensions are shown in Figures 20.7 and 20.8, respectively.

Sight Distance

Key to proper roadway design is to ensure that both the horizontal and vertical alignments of the roadway provide

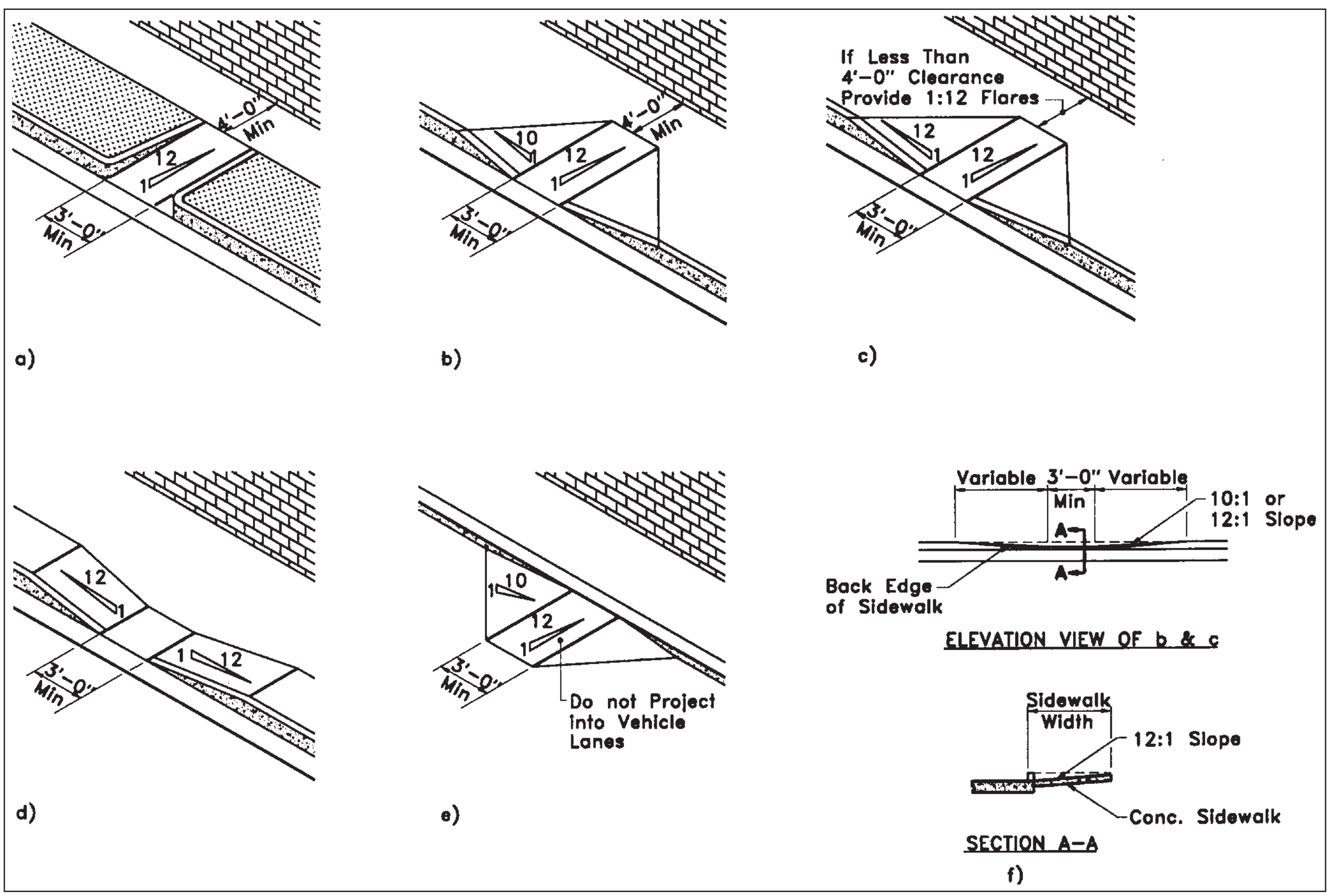

Figure 20.8 Curb-cut ramp details. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

adequate lines of sight for drivers. These lines of sight and associated sight distances should provide drivers with the lengths required to see, stop, and/or maneuver their vehicles with sufficient time to avoid striking objects, disabled vehicles, and even pedestrians in the travel lanes. As can be expected, pavement conditions, speed, fixed objects on the side of the road, horizontal curvature, gradients, and sag or crest vertical curve conditions all have an effect on stopping sight distances. On roads that may involve passing, sight distance is also affected by the need for sufficient time to maneuver back from the opposing travel lane.

Some types of sight distances to be considered during roadway design are:

- Stopping sight distance on horizontal curves
- Stopping sight distance on crest vertical curves
- Stopping sight distance on sag vertical curves
- Intersection sight distance
- Passing sight distance

Discussion of these relevant to low-speed street design is included later in this chapter.

CROSS-SECTIONAL ELEMENTS FOR LOCAL STREETS

Cross-sectional elements of a road include pavement, travel lanes, shoulders, medians, side slopes, curbs and gutters, drainage ditches (median and side ditches), sidewalks, and right-of-way widths. The specific elements included in the design of any road depend on the function and the particular locality. Design of such elements entails establishing the widths, depths, and cross slopes. These cross-sectional elements and their dimensions are identified on a detail drawing called the *typical cross section.*

It is possible for a project to require several typical cross sections. The cross-sectional elements may change to account for changes in the number of lanes, lane widths, superelevation, and other factors. Several examples of variations in cross-sectional elements are indicated in Figure 20.9, while an example of a typical section drawing that might be included in a construction package is shown in Figure 20.10.

Each detail should identify the location of the typical section by specifying the beginning and end stations. Typical section details are used by the design engineer to plot cross-section drawings for computing earthwork quantities, by the surveyor to stake out the road, and by the contractor to construct the road. Public review agencies use the typical section details to determine that the road design conforms to the local standards.

Many factors influence the cross-sectional design of local streets. These include the density of the development, availability of off-street parking, demographics, availability of shopping, and public services. The type of local street is also a major consideration. For the lower-category streets, many

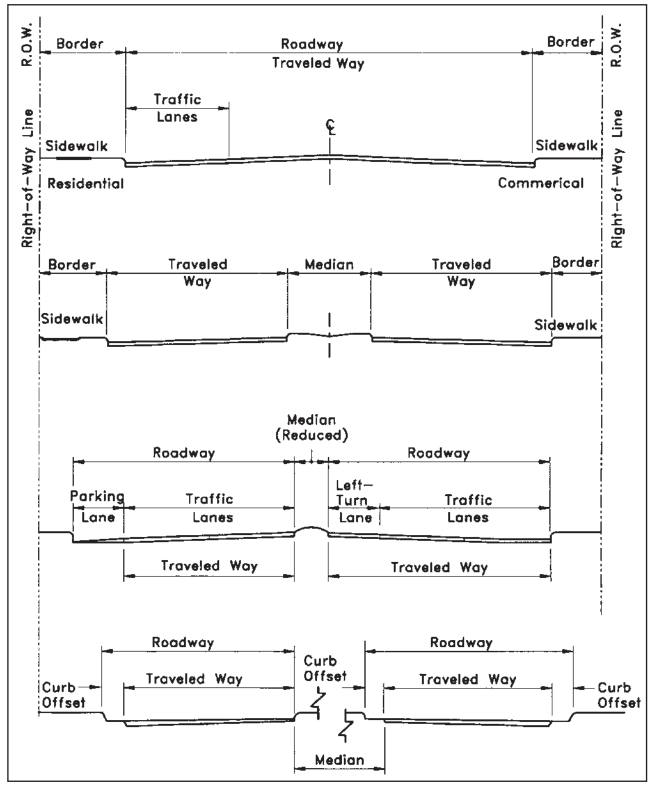

FIGURE 20.9 Cross-sectional elements—nomenclature for urban streets.

of the cross-section elements and their dimensions are usually included as part of the subdivision ordinance.

Profile Grade Line (PGL)

One important element identified on the typical section drawings is the *profile grade line* (PGL) or *theoretical grade line* (TGL), an arbitrarily selected reference point showing the proposed street elevations. While the PGL appears as a line in the profile view, in the typical section the PGL appears as a point (labeled as "P" in Figure 20.10). The PGL is selected for the convenience of design, stakeout, and construction. It can be the centerline of the road, edge of pavement, top of curb, or any other designated point as long as the horizontal and vertical relationship between the selected point and other elements of the typical section are known.

Lanes

The local subdivision ordinances typically specify the minimum number of lanes and their widths for a street, which is a function of the anticipated traffic volume. Traffic volume is directly related to land use. Therefore, local design standards may categorize the streets according to the number of dwelling units they serve. In commercial or retail areas, traffic volume may be related to the number of developed square feet of the retail/commercial neighborhood. Therefore, street lanes and their widths could be indirectly related to the size of the building.

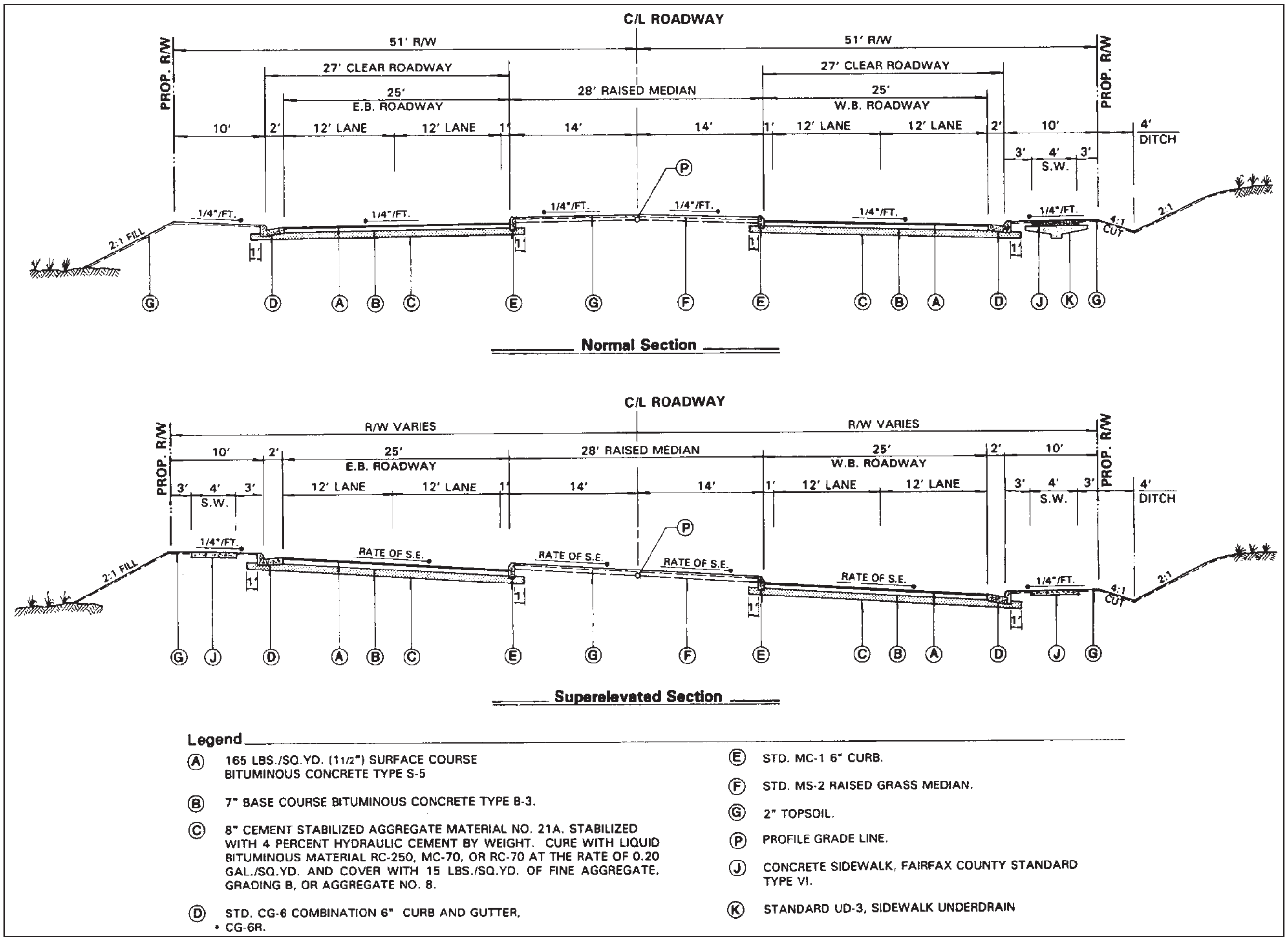

FIGURE 20.10 Typical section. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

To provide a minimum level of service[1] on a local street, the design must incorporate one unobstructed moving lane. As the development density of the area increases, the number of travel lanes may also need to increase. The length of travel also impacts the number of travel lanes needed to maintain a satisfactory level of service. Local streets are usually short, and some inconvenience to users of the street is acceptable. Additional lanes are required in those cases where on-street parking is allowed. However, the width of the parking lane should be narrower than the travel lane. Some general guidelines require parking lane widths on local streets to be 7 feet, while collector streets require an additional 1 foot of width in these lanes. When more than one lane is proposed in each direction, both collector and local streets should provide a minimum of 10-foot lane widths for moving traffic when it is anticipated that the primary class of vehicle using the road will be passenger vehicles, with only occasional small trucks. Where significant truck traffic is anticipated, or if larger semitrailers are expected on a fairly regular basis, a wider 11- or 12-foot lane width should be provided. Where only two lanes are proposed (one in each direction), 11-foot travel lanes are the requirement of most jurisdictions. Considering these recommendations, total travel lane widths on local streets vary from 22 to 24 feet (not including the parking lane). A typical range for collector street lanes with no parking is 22 to 26 feet.

[1]Level of service (LOS) is a qualitative measure of the operating conditions of the street. Oversimplified, it is a measure of the freedom of movement.

Cross Slope

A "normal crown" section has a high point in the middle (usually at the centerline), with the pavement cross slopes extending toward the outer edges of the pavement. In most conditions, the cross slopes are uniform across the total width of one direction of the pavement. However, for multilane roads, the cross slope remains uniform across a lane width, and any changes in the cross slope should occur at the edges of a travel lane.

For many local and collector streets, lanes on a normal crown section are typically sloped 2.0 percent toward the outer edge of pavement. This cross slope is sufficient to direct stormwater runoff into the gutters or to the side ditches and yet does not cause any significant driver discomfort because of the slight tilt of the vehicle. Cross slopes change when superelevation requirements are incorporated into the design.

Medians

Medians are used to increase the separation distance between opposing lanes of traffic and, in some cases, to provide refuge for pedestrians. In urban and suburban areas, medians may be raised concrete malls or painted areas approximately 4 to 12 feet wide. Wider median strips are typically grass strips with a ditch. In rural areas and on high-speed roads, medians can be 30 feet and wider. Medians are typically not used on local streets and are only occasionally used on collector streets. Their use is mostly in commercial areas where the traffic volumes are much higher and turning movements are more frequent and complex.

Design considerations include the spacing of median breaks. Median breaks allow traffic turning and crossover movements into and out of entrances, essentially providing more accessibility. Median breaks are also necessary for most intersecting streets. Guidelines for spacing between median breaks are provided by the governing public agency. These guidelines may only prescribe minimum distances for ordinary conditions and may be modified by the reviewing agency to accommodate the specific conditions. Each jurisdiction has minimum spacing requirements. This spacing is subject to the traffic volume on the through street, traffic volume making the turning movement, whether the turning movements are signalized, and the design speed of the through street. The design engineer must assess the impact of the median breaks on the level of service of the through street. A high number of median breaks and crossovers can significantly reduce the LOS on a given street, especially during peak hours.

The minimum spacing of median breaks can be viewed as the sum of the dimensions of median features that are required between two intersections. These elements include setback of the median noses to allow for proper turning radius at the intersections, length of each of the required left-turn lanes (especially when the median is narrow, eliminating the possibility of overlap between opposing left turn lanes), and length of the median transition between the left-turn lanes. Figure 20.11 illustrates the typical median geometry between two intersections and how it can dictate the minimum spacing between intersections/median breaks. In some cases, where a median width is approximately 28 feet or greater, the required left-turn lanes may be configured such that they overlap each other for some distance, thus allowing a reduction in the overall intersection spacing.

In any event, the minimum spacing dictated by the median features discussed here must be compared to the local standard for intersection/median break spacing. The greater of the two should then be used to govern design.

On commercial and retail projects there will be a desire to have numerous median breaks to allow for land access. However, local conditions and the reviewing agency may restrict the number of openings, which can impact the layout design of the project. The project manager needs to verify with the review agencies the location of the median breaks early in the planning stage.

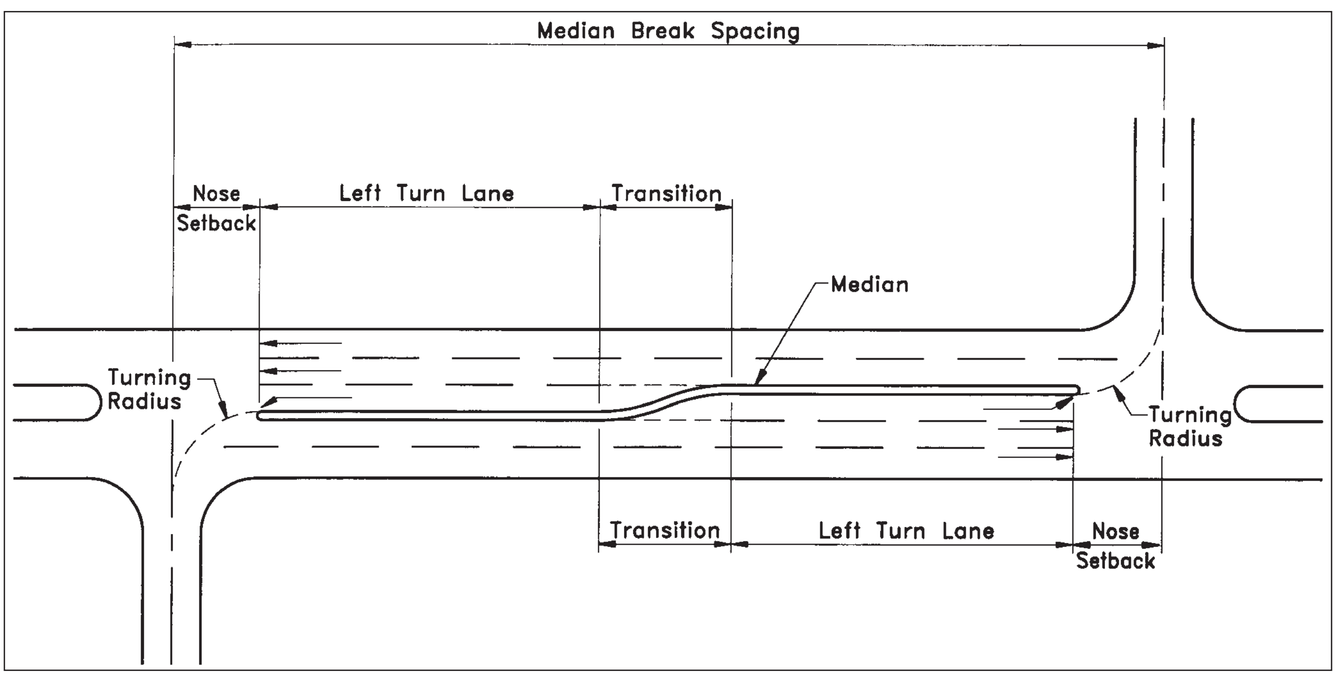

FIGURE 20.11 Median break spacing.

Another situation occasionally overlooked is when a site has frontage on an existing road with a median. In developing the site, a median break is anticipated in order for the opposite-side traffic to access the site, only to discover that the reviewing agency will not allow a median break at that location. Again, the project manager needs to verify such requirements with the reviewing agency early in the planning stage.

Curb and Gutter

In most urban areas, curb or combination curb and gutter streets are preferred. Their purpose is to facilitate drainage, separate traffic lanes from pedestrian walkways, contribute to the aesthetic appearance, and reduce maintenance. Several different types of curbs are often utilized depending on the locality and design speeds. Figure 20.12 shows various types of curbs.

For low-design-speed roads, barrier curbs are typically used, while roads with high design speeds utilize mountable curbs. These curbs are frequently used with traffic islands and along medians. Some localities permit the use of the combination curb and gutter where the gutter forces flow away from the face of the curb. These spill-type gutters facilitate drainage by forcing the flow away from the curb to prevent ponding water in the gutter area. Such curbs are normally used only in parking areas where the pavement typically has a nonuniform cross slope throughout the parking area.

Sidewalks and Utility Strips

Sidewalks are typically placed away from the curb near the right-of-way line. In residential areas, clear sidewalk widths can be as narrow as 3 feet, not including any utility strips adjacent to the curb, which are normally occupied by utilities and/or street hardware. However, a 5-foot-wide sidewalk is preferred, to accommodate wheelchair users. If a sidewalk is less than 5 feet wide, passing areas 5 feet by 5 feet spaced no more than 200 feet apart must be provided. In more commercial zones, sidewalk widths can vary between 10 and 15 feet from the curb to the building fronts. Longitudinal and cross slopes for sidewalks are governed by the requirements set forth in the ADAAG. According to the ADAAG, the maximum longitudinal slope of a sidewalk should not exceed 5 percent (1V:20H) with a maximum cross slope of 2 percent. In some cases, in order to meet existing topography or other constraints, it may be necessary to install sidewalks with a maximum longitudinal slope of 8.33 percent (1V:12H). These sidewalks are considered

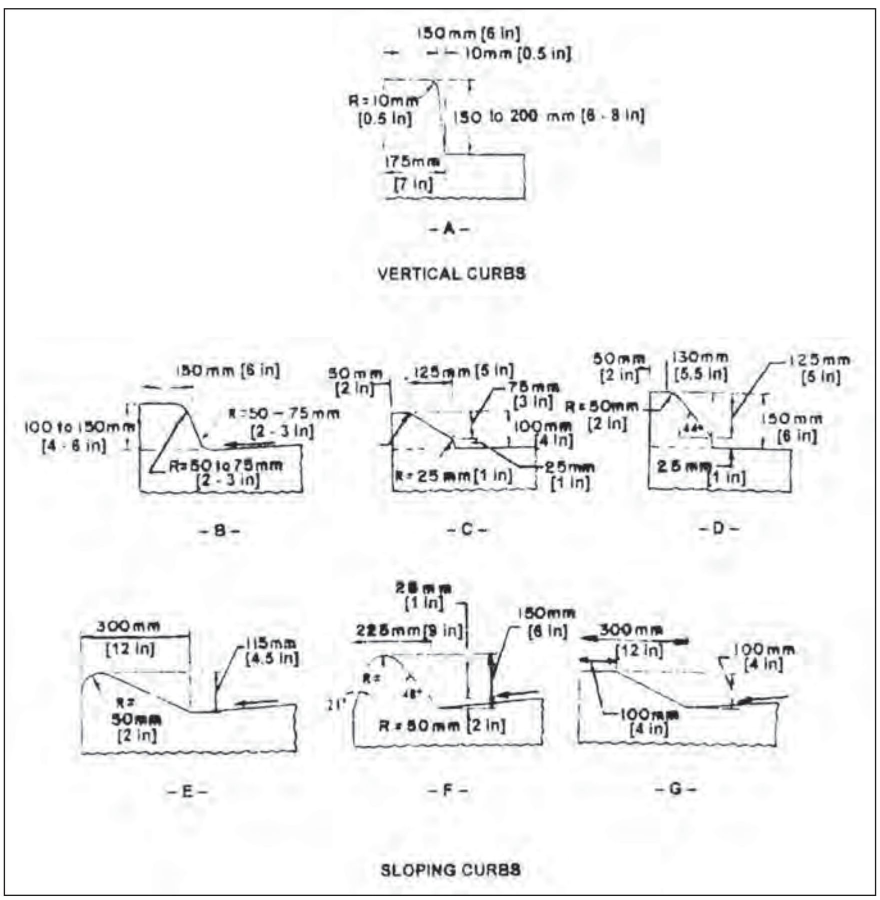

Figure 20.12 Common types of curb and gutter.

TABLE 20.2 Solar Reflectance Index (SRI) for Standard Paving Materials

MATERIAL	EMISSIVITY	REFLECTANCE	SRI
Typical new gray concrete	0.9	0.35	35
Typical weathered* gray concrete	0.9	0.20	19
Typical new white concrete	0.9	0.7	86
Typical weathered* white concrete	0.9	0.4	45
New asphalt	0.9	0.05	0
Weathered asphalt	0.9	0.10	6

*Reflectance of surfaces can be maintained with cleaning. Typical pressure washing of cementious materials can restore reflectance close to original value. Weathered values are based on no cleaning

ramps and should include level 5-foot-wide landings at a maximum spacing of 30 feet and handrail provisions. Sidewalk surfaces are commonly concrete or asphalt but may also be constructed of porous pavement—either open-grid,[2] gravel, or pervious concrete—subject to the prevailing design conditions including soils, climate, ownership/maintenance responsibility, and accessibility criteria. Material selection for sidewalks (and trails) is increasingly important, especially for projects utilizing a low-impact or sustainable design approach. Within USGBC's LEED-NC rating system, SS Credit 7.1, Heat Island Effect:[3] Non-Roof, requires 50 percent of the site hardscape to be shaded within five years, be constructed of open-grid pavement, have a Solar Reflectance Index (SRI)[4] of at least 29, or some combination of the three. Table 20.2 lists the SRI for several standard paving materials. Additional discussion of porous pavement is included under the "Pavement" section as well as in Chapter 22.

In residential developments, the area between the inside edge of the sidewalk and the curb is typically a grass strip used for placement of utility lines and other street hardware, such as fire hydrants and light poles. However, in commercial and retail areas this strip is typically paved for maintenance reasons. A utility strip width of 2 to 4 feet is reasonable; however, in areas of high land values this may not be practical. The ITE (1989)[5] recommends a minimum width of 5 to 6 feet to allow for tree planting. Streetside landscaping can contribute to heat island reduction strategies, discussed previously, by providing shade to both streets and sidewalks.

Shoulders, Side Slopes, and Ditches

In some low-density residential areas and in most rural areas, shoulders rather than curbs are normally used. Shoulders are 6 feet or wider and typically gravel. High-speed highways will have wider shoulders and are generally paved with asphalt.

The cross slope of the shoulder is typically steeper than the cross slope of the normal street section. Typical cross slopes are two to three times greater than normal pavement cross slope, on the order of 4 percent to 6 percent. Where roads are superelevated, shoulder cross slopes are dictated by the rollover between the outside edge of pavement and the beginning of the shoulder, that is, the algebraic difference between the pavement cross slope and the shoulder cross slope. For additional information on the treatment of shoulder cross slopes in superelevated sections, see Chapter 3 of AASHTO.

Side slopes are used for connecting the road section to natural ground. The slope gradient depends on the angle of repose of the soil and the available right-of-way width. In many cases the slopes are constructed at a 2H:1V ratio. However, flatter slopes are generally desirable if they can be provided within the available right-of-way. The type of mowing equipment also factors into determining the maximum side slope grades. Drainage ditches at the toe of the slope control surface water from the pavement in excavated areas or through an adjacent property in embankment areas.

Pavement

Pavement thickness is subject to prevailing soil conditions, climate, vehicle design loadings, and type of pavement. There

[2]Open-grid pavement is generally considered to be 50 percent impervious or less, with vegetation in the open areas.

[3]"Heat Island Effect" refers to the documented temperature increase that occurs in urban areas as a result of increased amounts of impervious surfaces including parking lots, streets, sidewalks, and buildings that tend to retain solar energy at a higher rate than pervious or vegetated surfaces.

[4]Solar Reflectance Index (SRI) is a measure of a material's ability to reject solar heat, as shown by a small temperature rise. It is given on a scale of 0 (black) to 100 (white), although exceedingly "hot" or "cool" materials may have values outside this scale. SRI values are commonly available from material manufacturers/providers and available tables, or may be field-verified by measuring the reflectance and emittance of the material according to applicable ASTM standards.

[5]*Guidelines for Subdivision Residential Street Design,* 1989.

are three basic types of pavement: flexible, rigid, and composite (see Figure 20.13).

Flexible and composite pavements consist of two or more of the following layers:

- *Subgrade:* The natural soil material where the upper layers rest.
- *Subbase:* Optional layer used to augment the strength of the subgrade. It consists of a compacted granular material that may be treated with admixtures to achieve certain strength characteristics required in specific conditions. Additionally, the subbase acts to reduce frost action or as a filter to prevent intrusion of fine-grained roadbed soils into the base course.

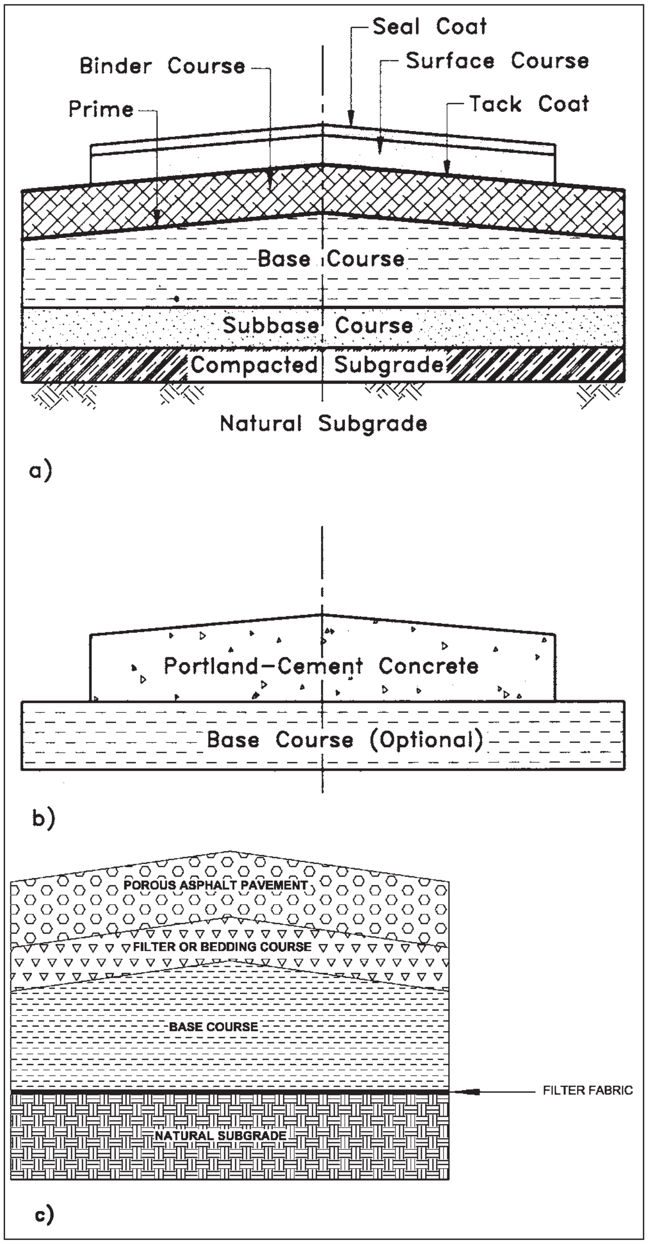

FIGURE 20.13 Typical pavement sections. (Yoder. *Principles of Pavement Design,* 2nd ed. Reprinted by permission of John Wiley & Sons)

- *Base course:* Constructed on top of the subbase or subgrade. For flexible pavements, it consists of granular material such as crushed stone or gravel. The specifications for the flexible pavement base course are more rigorous than that of the subbase in terms of strength, hardness, gradation, and aggregate types. In composite pavements, the base course consists of a concrete base slab, typically unreinforced, placed directly on the subgrade without a subbase course.
- *Surface course:* Top course of the pavement section consisting of a mixture of mineral aggregates and asphaltic materials. The purpose of the surface course is to provide a smooth riding surface, resist the wear and tear from traffic, provide skid resistance to vehicles, and prevent excessive water from penetrating into the base course. The surface course may be further subdivided into binder and top courses. The binder course typically consists of an asphaltic mixture with a larger aggregate size for additional strength, while the top course utilizes a smaller aggregate mix to provide a smoother riding surface.

Depending on the site conditions and the performance of the subgrade, the reasonable range of thickness of the subbase is 6 to 8 inches. Base course thickness ranges from 3 to 6 inches for flexible pavements and 6 to 9 inches for composite pavements, while the surface course is 1 to 3 inches for lower-category-type roads.

Rigid pavements typically consist of a pavement slab of Portland cement concrete and a subbase layer. However, the subbase layer is omitted when the subgrade material is granular. Depending on the amount of steel reinforcement, rigid pavement can be classed as plain concrete, simply reinforced concrete, and continuously reinforced concrete. Subbase depths under reasonable conditions may range from 4 to 8 inches, and the concrete thickness can range from 6 to 12 inches.

In addition to these pavement types, which are considered to be impervious surfaces (i.e., stormwater will run off rather than seep through), a porous pavement design could be considered under certain circumstances. Porous pavements may be constructed of either porous asphalt or pervious concrete. In both cases, the finished pavement is placed over an infiltration bed consisting of open-graded gravel with a high percentage of voids. The advantages of utilizing porous pavement include:

- Filtering of stormwater runoff
- Fewer pipes/inlets need be constructed
- Better skid resistance (due to the open-graded nature of the surface and the fact that water does not sit on the pavement surface)

However, in order to be successfully implemented, care must be taken in site selection and construction. Porous pavements are not recommended in areas with poor geology (i.e., high ground water tables or low-permeability underlying soils), in areas that would be susceptible to a high incidence of contaminant spills (such as a refueling station), in high-traffic areas; or in areas that might be coated or paved over (such as private driveways). In addition, in order to maintain effectiveness, porous pavements should be vacuum swept and/or power washed twice per year, and sand or gravel should not be used for deicing/traction in cold-weather climates. For these reasons, porous pavements are most applicable for use in parking lots and low-volume access roads.

Some local criteria may provide a range of alternative pavement designs for local and residential streets that can be used directly or modified, if necessary, to accommodate specific site conditions.

Right-of-Way Widths on Local Streets

Right-of-way on a local street need only be wide enough to accommodate the pavement and other facilities and uses provided by the land development project or as required by the approving governmental agency. Items for consideration when making a determination on the proper width include water mains, storm and sanitary sewers, power lines, other utilities, roadway signs, and sidewalks. In climates susceptible to heavy snowfall, provisions for storage of plowed snow could affect right-of-way widths. Local controls and requirements of planning boards and other government bodies often dictate predetermined widths without regard to functional needs.

HORIZONTAL ALIGNMENT

The street layout is constrained by such things as topography, needed connections to existing street networks, and required access to adjacent land. The optimal layout of the development must produce maximum lot yield (buildable lots) with consideration for aesthetics and market attraction. Additionally, required improvements to any existing streets may affect the proposed street layout. All of these constraints factor into the horizontal alignment of the proposed streets.

Circular Curves

Horizontal alignment of streets and roadways is critical to the subdivision of land. For arterial streets and highways, this alignment has an effect on design speed and sight distance. For a local street, speed is not a significant controlling design factor in setting the alignment. Rather, the alignment is typically determined by the designer's ability to take advantage of existing topography, while maintaining a safe, functional street. The horizontal alignment is composed of a series of two basic types of geometric sections: straight tangents and curves. The curve used on local streets is a simple circular curve. This is a section of a circle having a constant radius, as opposed to spiral curves, which are curves of vary-

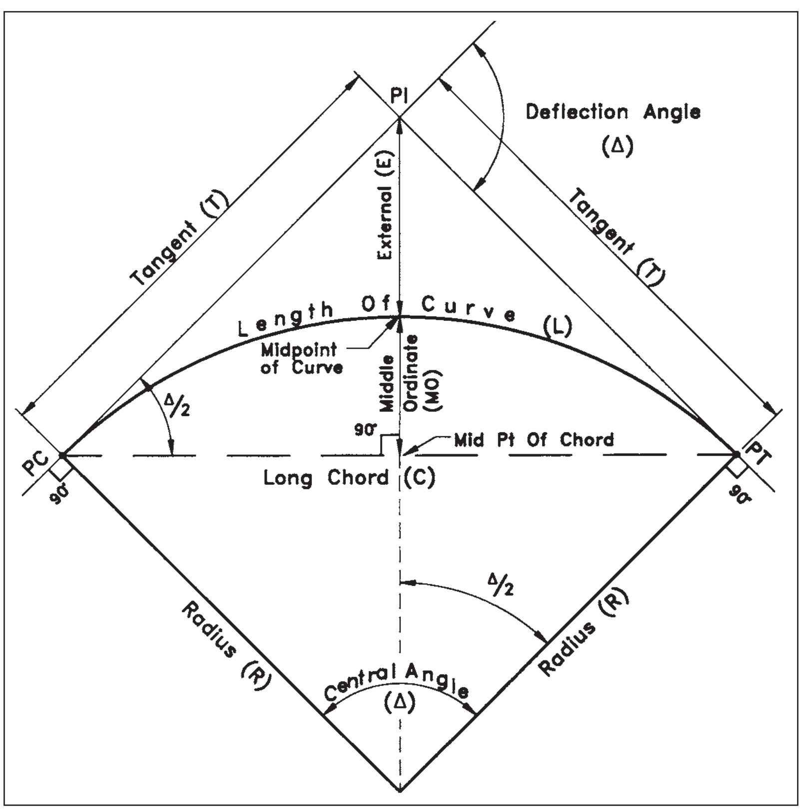

FIGURE 20.14 Elements of a circular curve.

ing radius. Figure 20.14 shows the basic elements of the circular curve that are important to street design.

Two tangents of different direction are joined together by a circular arc of constant radius R at two points. The point at which the tangent ends and the curve begins is labeled the point of curvature PC. The point at which the curve ends and the next tangent begins is labeled the point of tangency PT. The tangents intersect at the PI, point of intersection. The deflection angle Δ is the exterior angle formed between the two tangents at the PI. The angle formed by a tangent and a line from the PC or PT to the curve center CC is always precisely 90°. Any angle other than 90° produces a flaw in the geometry and is not a true representation of the circle-tangent relationship.

There are seven basic components of the circular curve. Two have been identified: radius R and deflection angle Δ. The remaining components are as follows.

Length of curve L is the arc length from PC to PT.

$$L = \Delta_{\text{(in radians)}} \times R \tag{20.1}$$

or

$$L = \frac{\Delta_{\text{(in degrees)}} \times \pi R}{180}$$

Tangent distance T is the distance from the PC or PT to the PI (both distances are equal).

$$T = R \tan\left(\frac{\Delta}{2}\right) \tag{20.2}$$

Long chord C is the distance measured along a straight line from the PC to PT.

$$C = 2\,R \sin\left(\frac{\Delta}{2}\right) = 2\,T \cos\left(\frac{\Delta}{2}\right) \tag{20.3}$$

External distance E is the distance from the PI to the midpoint on the curve.

$$E = R\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right) = T \tan\left(\frac{\Delta}{4}\right) \tag{20.4}$$

Middle ordinate MO is the distance from the midpoint on the curve to the midpoint on the long chord.

$$\text{MO} = R\left(1 - \cos\left(\frac{\Delta}{2}\right)\right) \tag{20.5}$$

The length of arc of a simple curve bears the same proportion to the circumference of a full circle of same radius as the central angle subtended by the arc bears to 360°. Simply stated,

$$\frac{AB}{2\,\pi\,R} = \frac{\Delta}{360°} \tag{20.6}$$

The degree of curvature, like the radius, is a measure of the sharpness of curvature. The degree of curve by arc definition is the amount of central angle (Δ) subtended by 100 feet of arc (see Figure 20.15). Letting the arc distance AB = 100 feet in Equation 20.6 defines the degree of curve D as

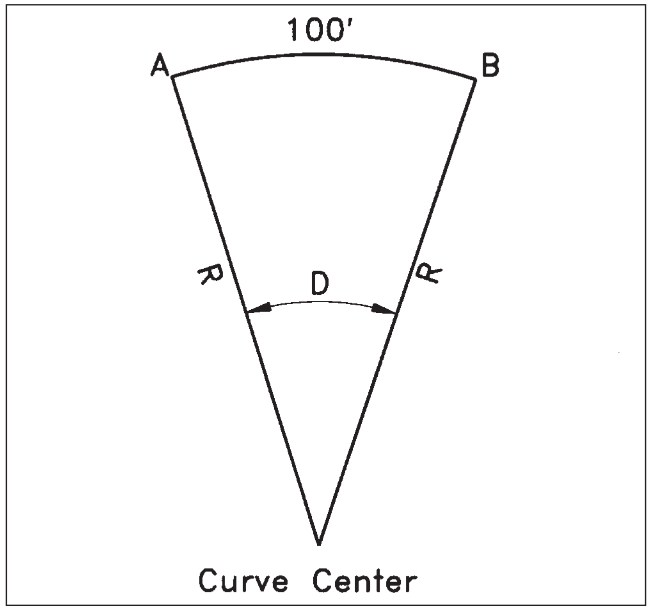

Figure 20.15 Degree of curve by arc definition.

$$D = \frac{5729.58}{R} \tag{20.7}$$

As an example, a curve with a 1637-foot radius is equivalent to a 3½° curve (i.e., 5729.58 ÷ 1637). A smaller 572.96-foot radius would require a 10° angle to create a 100-foot arc length, that is, D = 10° (see Figure 20.16). Notice that according to Equation 20.7 and the preceding example, as the radius decreases the degree of curve increases.

There are two things worth noting regarding degree of curvature. First, the definition described here serves for streets and highways and is known as the *highway definition*. (A separate definition based on a 100-foot chord length instead of arc length defines degree of curve for railroad curves and is known as the *railroad definition*.) Second, degree of curvature is restricted to English units of measure. In the metric system of measurement, degree of curve is not defined and not used.

Compound Curves

The connection of simple curves of different radii in series with the centers on the same side of a common tangent forms curves known as *compound curves*. Each curve has a different radius and connects at a common point of tangency referred to as the point of compound curvature PCC. As shown in Figure 20.17, the two curve centers and the PCC are collinear. In a compound curve there are three pairs of tangents; the tangents t_1 and t_2, associated with each individual curve, and the long tangents T, which includes both curves. Unlike the simple curve, the long tangents may not be equal. The following equations are used in computing

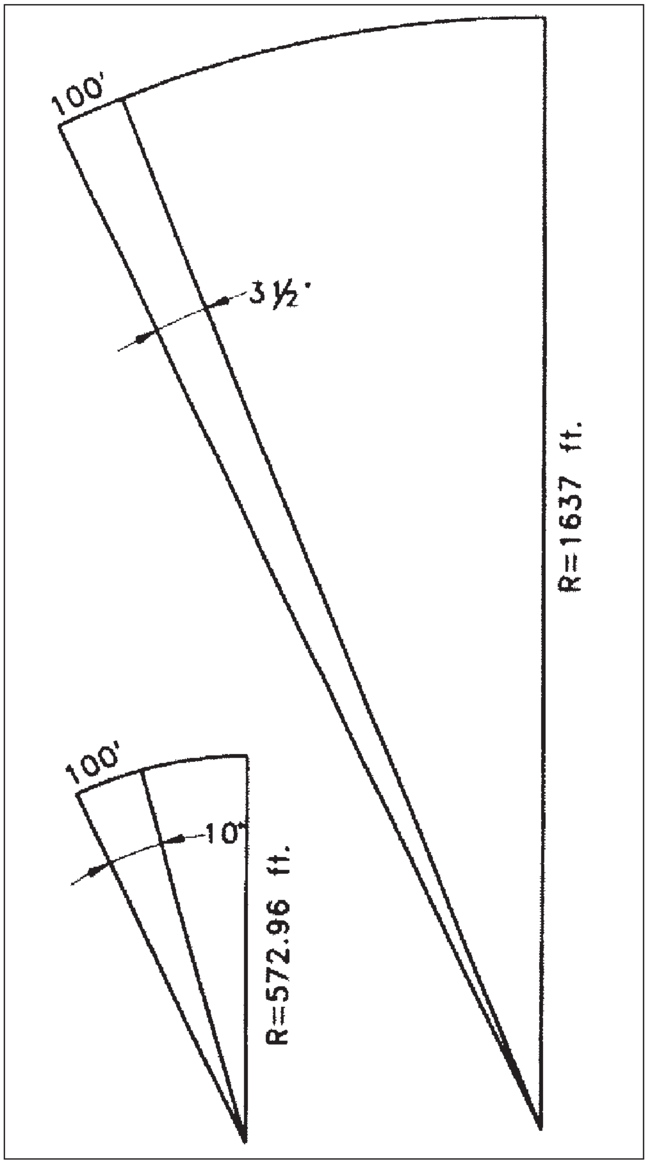

FIGURE 20.16 Comparison of degree of curvature with radius.

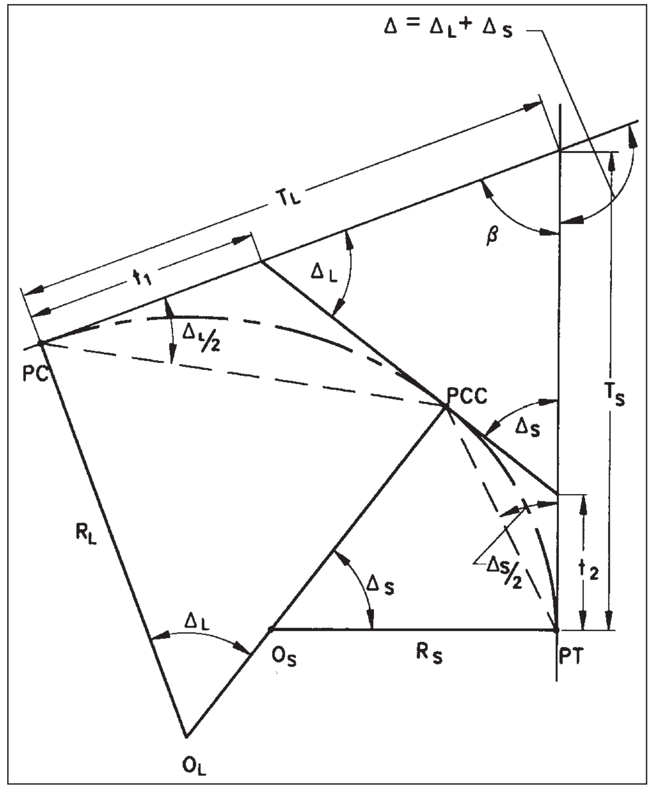

FIGURE 20.17 Elements of a compound curve.

elements of the compound curve with respect to the nomenclature of Figure 20.17.

$$
\begin{aligned}
\Delta &= \Delta_L + \Delta_S \\
T_L &= \frac{R_S - R_L \cos\Delta + (R_L - R_S)\cos\Delta_S}{\sin\Delta} \\
T_S &= \frac{R_L - R_S \cos\Delta - (R_L - R_S)\cos\Delta_L}{\sin\Delta} \qquad (20.8) \\
\tan\left(\frac{\Delta_L}{2}\right) &= \frac{T_S \sin\Delta - R_S(1-\cos\Delta)}{T_L + T_S\cos\Delta - R_S\sin\Delta} \\
\tan\left(\frac{\Delta_S}{2}\right) &= \frac{R_L(1-\cos\Delta) - T_L\sin\Delta}{R_L\sin\Delta - T_L\cos\Delta - T_S}
\end{aligned}
$$

Compound curves are typically used near at-grade intersections and to accommodate the desired street alignment, especially in difficult topographic areas and in high-density developments where the road alignment may be constrained by other physical features. At the speeds encountered on local streets, the effects of a sudden change in curvature at the PCC may not be as pronounced as on high-speed highways. To decrease rider discomfort through a compound curve, the radii of the two curves should not differ considerably. AASHTO recommends that the ratio of the two radii be less than 2:1 at intersections.

Reverse Curves

Two consecutive curves with centers on opposite sides of the common tangent is known as a *reverse curve*. These curves join at a common point of tangency called the *point of reverse curvature* PRC. To be geometrically correct, the two curve centers and the PRC must be collinear. Reverse curves are not recommended on high-speed highways or roads where superelevation is required. In such cases it is desirable to insert a minimum tangent length of 100 feet between curves to allow for transition of superelevation between the curves. This is also a safer design for the driver to negotiate the vehicle through the directional change. When installed with the tangent section between curves, the result is two simple curves used to change the direction of travel. Figure 20.18 shows a schematic of a reverse curve.

Superelevation

Superelevation is the tilting or banking of the roadway around a horizontal curve to counter the outward centripetal

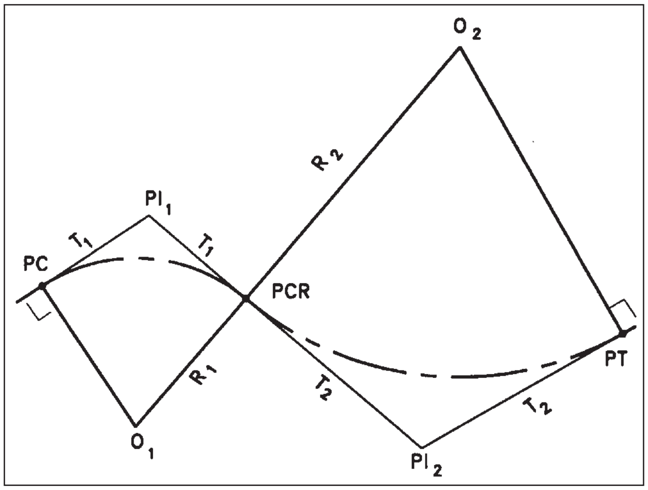

Figure 20.18 Elements of a reverse curve.

forces on a vehicle as it travels along the curve. Superelevation is an important element in the design of arterial streets and highways, but is rarely a design requirement for minor roads such as local streets and collectors. The reason is that in its attempt to improve riding comfort, superelevation promotes speeding and, hence, can be a safety liability on residential streets. At design speeds of 25 mph and below, the reduction in riding comfort for non-superelevated pavement is not significant. However, others might argue that superelevation is needed on low-speed streets for the safety of the vehicle and occupants. Rather than superelevate the road beyond normal section cross slopes, a compromise is to superelevate the road only to the extent where the outside cross slope equals the cross slope of the inside lanes at normal section. In practice this is referred to as *reverse crown.* On some roads, such as major collectors and minor arterials, superelevation is a requirement and the design must conform to the applicable criteria.

For more detailed information regarding superelevation, refer to Chapter 3 of AASHTO's *A Policy on Geometric Design of Highways and Streets.*

Sight Distance on Horizontal Curves

In residential areas, children play in or near the street and pedestrians tend to cross the streets at their convenience rather than at designated crosswalks and intersections. Such common situations emphasize the need for adequate *stopping sight distance* (S). Assessing adequate stopping sight distance is further complicated by on-street parking as well as trees planted along the side and median of the road. Often, adequate sight distance is provided with the initial design, and trees and shrubs are placed later. As the trees and shrubs mature, sight distance is significantly reduced. Other factors impacting sight distance include barriers to the line of sight such as ground slopes, buildings, and vertical grades in combination with horizontal curves.

Stopping sight distance for a horizontal curve is the chord length of the centerline of the inside lane of the pavement with the stopping distance measured along the arc length of the curve. This is the actual distance the vehicle travels during the reaction and stopping time. Figure 20.19 illustrates the location of the sight distance line and the stopping distance. The relationship between the middle ordinate distance, the stopping distance, and the curvature is obtained from Equations 20.5 and 20.6.

$$\mathrm{MO} = R\left(1 - \cos\left(\frac{28.65}{R}S\right)\right) \tag{20.9}$$

where MO is the middle ordinate (feet), S is the stopping distance (feet), and R is the curve radius (feet). One must recognize that the figure shows how to determine adequate sight distance in the horizontal plane. Vertical alignment of the street is also a factor, and this method is not applicable if the horizontal curve is near a vertical curve.

Another type of sight distance is *passing sight distance,* which is the sight distance needed for a vehicle to safely and comfortably pass another vehicle by temporarily using the opposing lane. Passing sight distance is generally required only on two-lane arterial highways, and the distances required are significantly greater than stopping sight distance.

VERTICAL ALIGNMENT

Vertical Curves

Vertical alignment of streets is accomplished by connecting straight tangent sections with parabolic curves rather than circular curves. Parabolic curves allow the street alignment to better adapt to the topography while providing a constant rate of grade change for a smooth, safe, and aesthetically pleasing design. In all but very rare, unusual cases, street design uses equal tangent vertical curves, called *symmetrical vertical curves.*

Figure 20.20 shows four types of vertical curves possible with different combinations of positive and negative grades. Crest vertical curves have entrance grades algebraically greater than the exit grades, while in sag vertical curves the exit grades are algebraically greater than the entrance grades. Figure 20.20 shows crest vertical curves at the top and sag vertical curves below.

A vertical curve consists of two straight tangent segments with grades designated as g_1 and g_2, and the connecting vertical curve (see Figure 20.21). The curve is tangent to the straight segments at the PVC (point of vertical curvature) and PVT (point of vertical tangency). The tangents intersect at the point of vertical intersection PVI. The length of the vertical curve is the horizontal distance between the PVC and PVT. It is not measured along the curve itself. For symmetrical vertical curves, the horizontal distances from the PVC to PVI and PVI to PVT are equal.

The general equation for any vertical curve is:

$$y = \frac{1}{2}\left(\frac{g_2 - g_1}{L}\right)x^2 + g_1x + \mathrm{PVC_{Elev}} \tag{20.10}$$

where y is the elevation of the point on the vertical curve a horizontal distance x away from the PVC. Frequently in

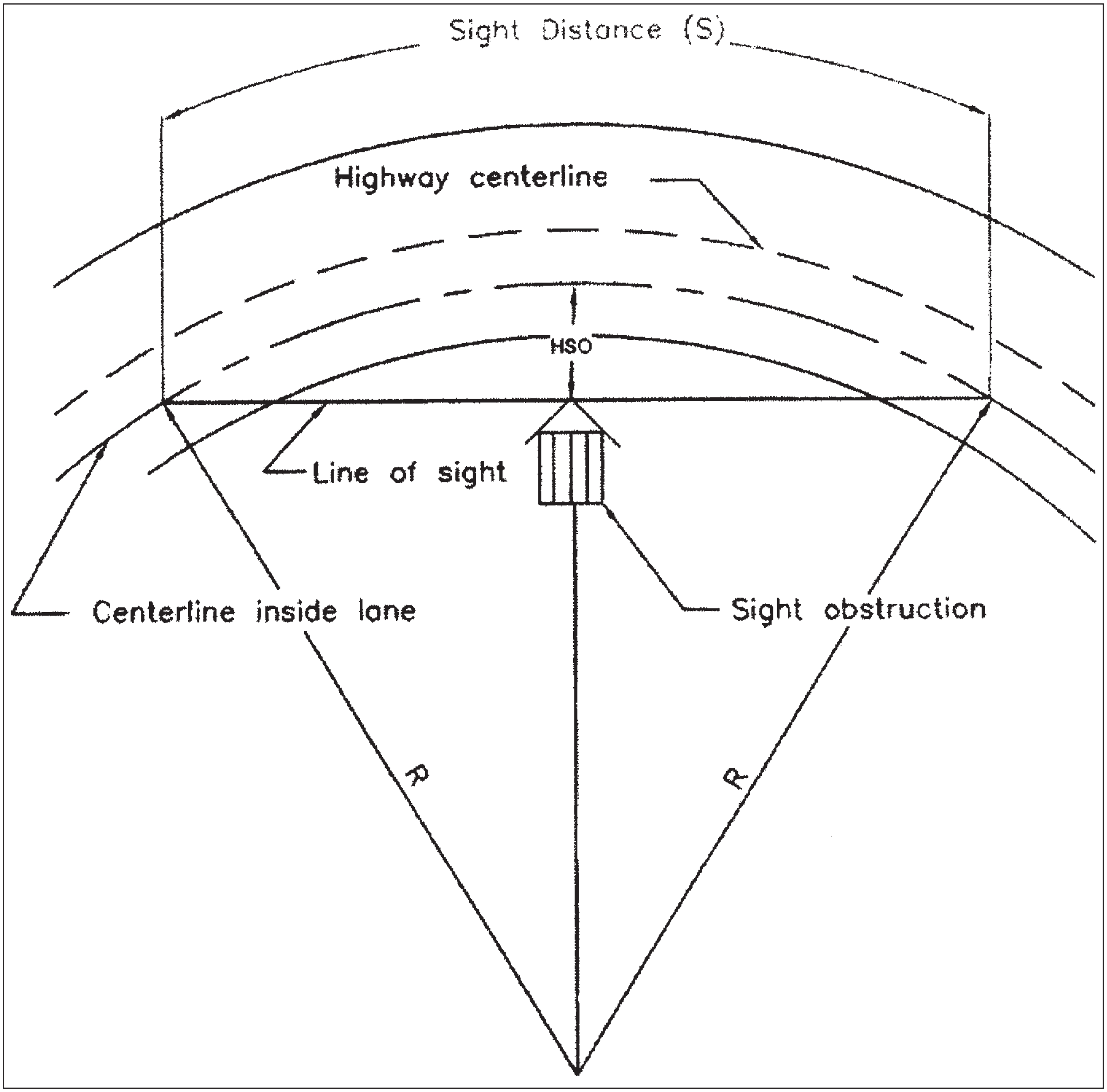

FIGURE 20.19 Sight distance along a horizontal curve. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

highway design manuals and textbooks the algebraic difference of grades $g_2 - g_1$ is designated as A.

Figure 20.2129

shows the application of the mathematical terms. The first term, the tangent offset $= Ax^2/2L$, represents the vertical distance from the point on the curve to the tangent represented by g_1. The g_1x term is the vertical distance between the point on the tangent and the PVC, and the summation $g_1x + \text{PVC}_{\text{Elev}}$ gives the tangent elevation.

The center of the parabola is midway between the vertex, that is, PVI, and the long chord. The middle ordinate (MO), the vertical distance from the long chord to the curve, is equal to the external E, the vertical distance from the curve to the PVI, and is given as:

$$E = \text{MO} = \frac{A\,L}{8} \tag{20.11}$$

The relationship between the tangent offset d at any point on the vertical curve and the external is given as:

$$d = \frac{1}{2}\left(\frac{A}{L}(x^2)\right) = E\left(\frac{x}{L/2}\right)^2 \tag{20.12}$$

If x is the distance measured from the PVC, d is the vertical distance measured from the connecting tangent. On the

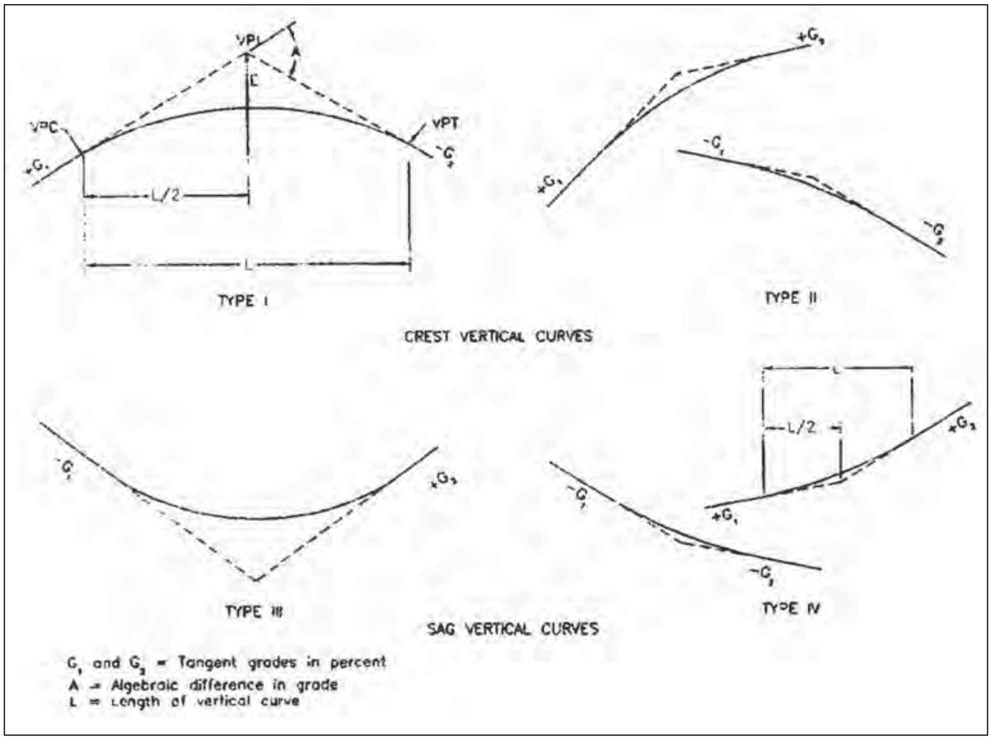

Figure 20.20 Various types of vertical curves. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials,Washington, DC. Used by permission)

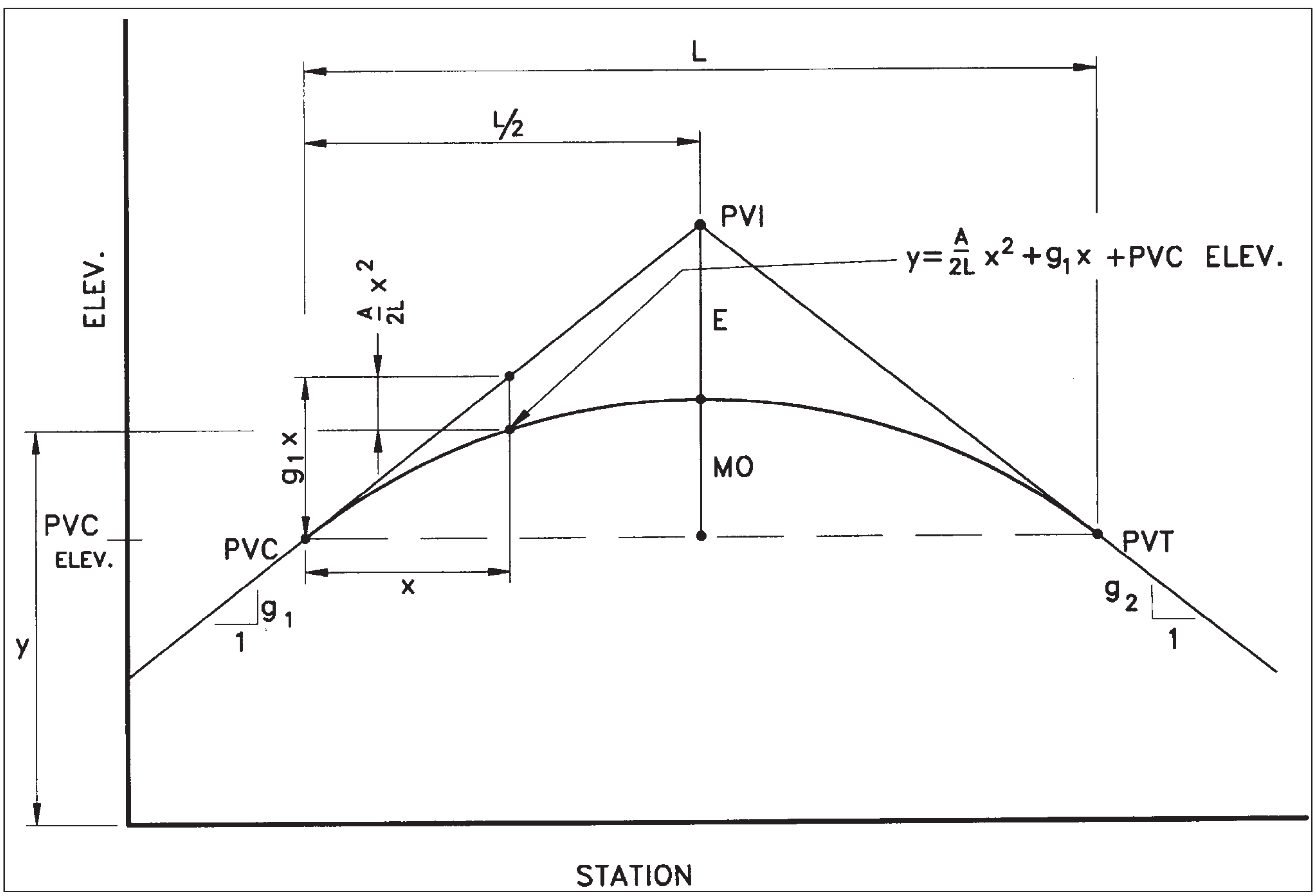

Figure 20.21 Schematic diagram for symmetrical vertical curve.

other hand, if x is measured from the PVT, d is the distance measured from the tangent connecting the PVT. Note that the offsets from the two tangents are symmetrical with respect to the PVI.

The distance from the PVC to the high point of a crest curve (or low point of a sag curve) is:

$$x = -\frac{g_1 L}{A} \tag{20.13}$$

Substituting this value into Equation 20.10 sets the elevation at the high or low point. Equation 20.13 shows that for type I and III curves, if $g_1 = g_2$ the high/low point location is in the middle of the curve, and if $g_1 \neq g_2$ the high/low point is located on the side of the PVI with the flatter grade.

Sight Distance on Crest Vertical Curves

Design of crest vertical curves includes the provision for safe stopping distances, rider comfort, and general appearance. However, in nearly all cases, stopping sight distance is the controlling factor. The safe stopping distance requires a minimum length of curve fitted to the given tangents and design speed. The greater the algebraic difference in grade between the tangents, the longer the vertical curve must be to provide adequate sight distance.

Two cases exist with regard to sight distance and the length of a vertical curve:

Case I exists where the required sight distance S is less than the length of the vertical curve L, as shown in Figure 20.22. The applicable equation is:

CASE I: when $S < L$:

$$L = \frac{AS^2}{200\,(\sqrt{H_1} + \sqrt{H_2})^2} \tag{20.14}$$

$$L = \frac{AS^2}{2158} \text{ (for } H_1 = 3.5 \text{ ft, } H_2 = 2.0 \text{ ft)}$$

Case II (shown in Figure 20.23) occurs when the required sight distance is greater than the length of the vertical curve, that is, $S > L$:

CASE II: when $S > L$:

$$L = 2\,S - \frac{200(\sqrt{H_1} + \sqrt{H_2})^2}{A} \tag{20.15}$$

$$L = 2\,S - \frac{2158}{A} \text{ (for } H_1 = 3.5 \text{ ft, } H_2 = 2.0 \text{ ft)}$$

where:

L = length of the vertical curve
S = sight distance in feet
A = algebraic difference in grades where $A = G_2 - G_1$ (grades are given in percent)
H_1 = height of eye and H_2 = height of object (AASHTO recommends $H_1 = 3.5$ ft and $H_2 = 2.0$ ft)

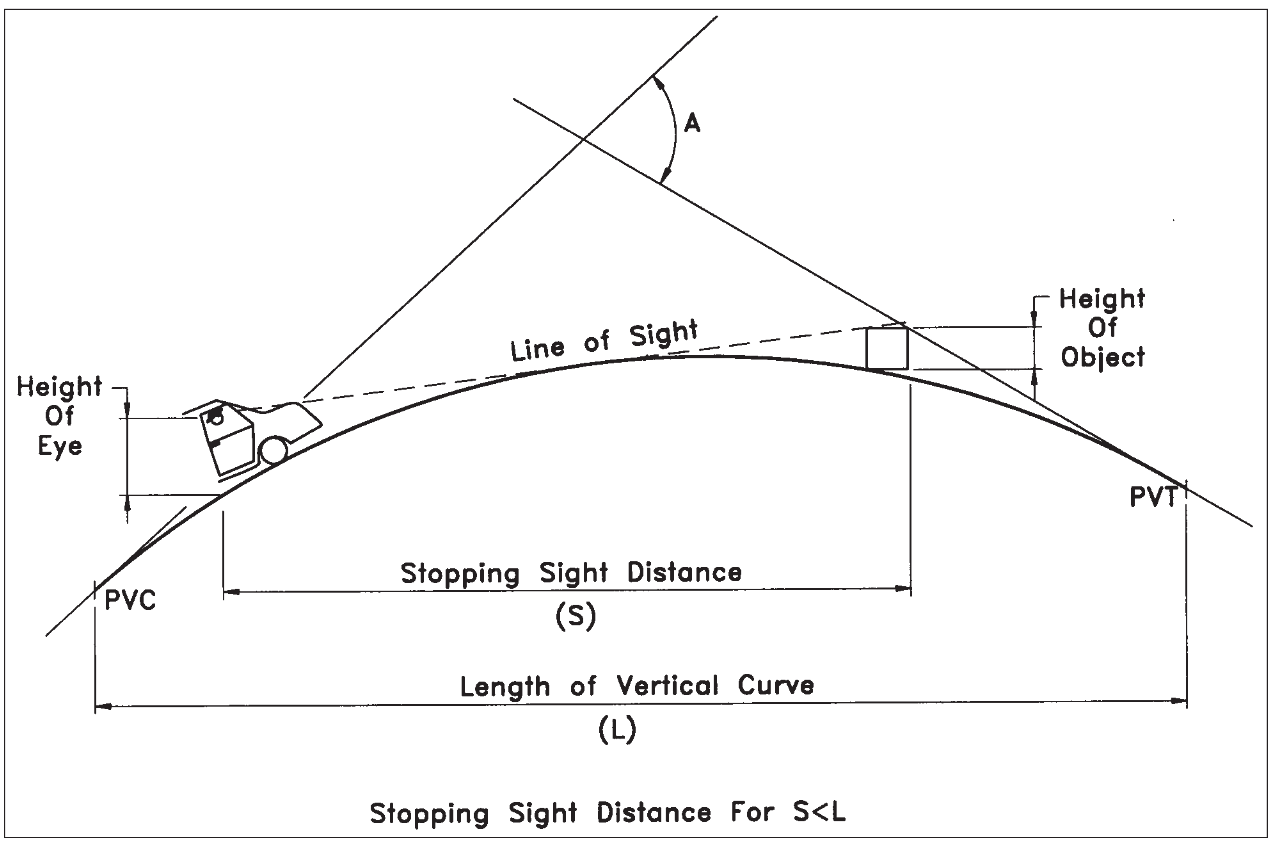

FIGURE 20.22 Stopping sight distance when $S < L$.

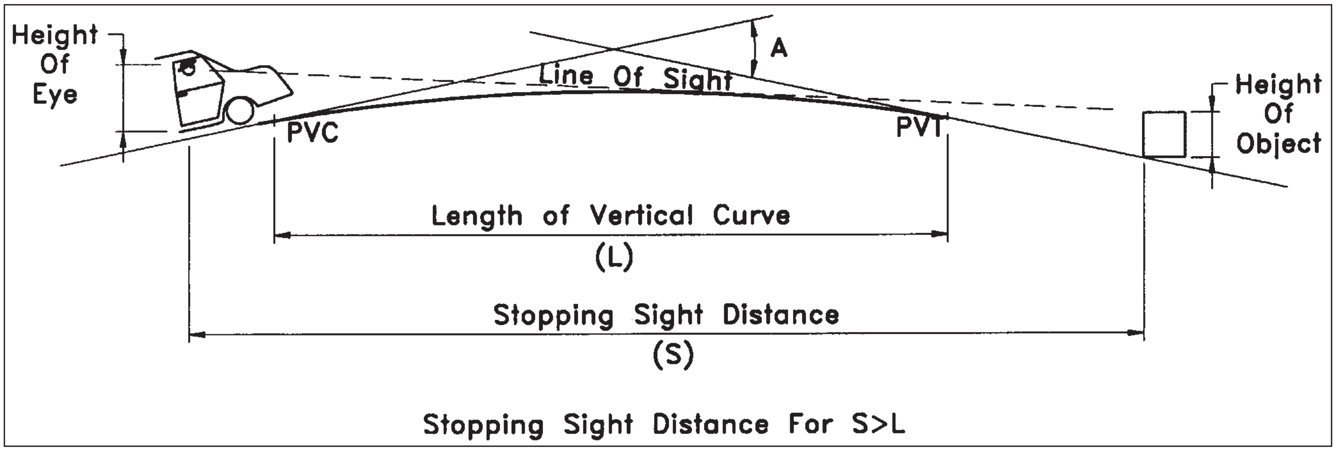

Figure 20.23 Stopping sight distance when $S > L$.

Assume either the $S < L$ or $S > L$ case and use the appropriate equation (Equation 20.14 or 20.15, according to the assumption) to find curve length L. If the computed curve length is contrary to the assumed condition, use the other equation to recalculate the correct length.

Finding a minimum curve length given g_1, g_2 and the design speed requires knowing the stopping sight distance obtained from:

$$S = 1.47tV + \frac{V^2}{30(f \pm G)} \qquad (20.16)$$

where

S = stopping sight distance (ft)
t = reaction time (sec)
V = initial travel speed (mph)
f = coefficient of friction between tires and road
G = longitudinal street slope (ft/ft)

A frequently used parameter for relating stopping sight distances to the length of a vertical curve is the ratio of the length of curve to the algebraic difference in tangent grades $K = L/A$. Parameter K is a measure of curvature in that the ratio represents the horizontal distance required to generate a 1 percent change in grade and A is the algebraic difference of the tangent grades in percent (%).

In lieu of using the equations to determine the minimum length of vertical curve, AASHTO provides K values for various design speeds. These K values can then be used to determine the minimum length of vertical curve required for the given conditions. K values are derived from Equation 20.14, which can be written as $L = KA$, where $K = S^2/2158$.

Most design standards maintain absolute minimum distances for the length of a vertical curve when S is greater than L. For local and collector streets this minimum may typically be between 50 and 200 feet. Local ordinances or state highway criteria may require additional increases in stopping distance based on development density, local climatic conditions, and other experiences. The engineer should check the local design criteria to determine the minimum vertical curve requirements.

In addition to stopping sight distance on crest vertical curves, another type of sight distance is passing sight distance, as discussed under "Horizontal Alignment." In general, passing sight distance is required only for two-lane arterial streets and highways. Sometimes it is more economical to create no-passing zones near crest vertical curves, with proper signing and striping, to keep costs manageable. For more detailed information regarding passing sight distance, refer to Chapter 3 of AASHTO's *A Policy on Geometric Design of Highways and Streets.*

Sight Distance on Sag Vertical Curves

Factors controlling the lengths of sag vertical curves include sight distance related to vehicle headlights, drainage, and rider comfort. Equations for determining sag vertical curve lengths for minimum sight distances are based on the illuminated area from the average car headlight beam. The headlight beam is assumed to be 2 feet high and directed 1° upward from the longitudinal axis of the vehicle. Equations 20.17 and 20.18 are for use on sag vertical curves. AASHTO provides a table containing the appropriate values for K and stopping sight distances for sag vertical curves.

$$L = \frac{AS^2}{400 + 3.5S} \qquad (20.17)$$

when $S < L$.

$$L = 2\,S - \frac{400 + 3.5S}{A} \qquad (20.18)$$

when $S > L$.

On sag curves, drainage is a more critical factor than for crest vertical curves. AASHTO guidelines suggest providing a minimum grade of 0.3 percent within 50 feet of the low point to ensure adequate drainage. This corresponds to a K value of 167. Sag vertical curves with K values of 167 and greater are an indication that the curve may be too flat in the sump area to properly drain. This can create safety and drainage problems, especially on curbed streets. The 167 value is not a minimum, but rather a guide indicating that attention to gradelines is warranted.

GEOMETRIC PROPERTIES OF AT-GRADE INTERSECTIONS

Intersections are points where two or more streets or highways join or cross. The three basic types of intersections in use are at-grade, grade separated, and interchange. At-grade intersections are used for joining local, collector, and many minor arterial streets, whereas the latter two types are more generally used on high-speed highways or arterials. Except for certain unusual situations, the number of legs at any one intersection should not exceed four.

Intersections affect the overall performance of the intersecting roads. A measure of the operational performance includes the speed of movement through the intersection. The movement speed determines the capacity and thus affects the suitability of a street to function as intended. In other words, the level of service of a street is greatly affected by the level of service of the intersection. Design features that impact the design of at-grade intersections include:

- Adequate corner sight distances
- Angle of approach
- Matching pavement grades on approaches
- Width of the intersection
- Radius of curvature of the curb returns
- Need for auxiliary lanes or channelization
- Intersection control
- Need for traffic-calming measures

Physical elements, traffic, human factors, and economics encompass items for consideration in the design process of at-grade intersections. For local streets in residential areas the major design considerations are adequate corner sight distances, matching street grades, and minimum radius of the curb returns. The complexities of intersection design increase as the traffic, bicycle, and pedestrian volumes increase, and the potential rate of conflicts (pedestrian-vehicle, pedestrian-bicycle, vehicle-bicycle, and vehicle-vehicle) increases.

The three basic types of at-grade intersection are the “T” intersection, the four-leg intersection, and the multileg intersection. Each type has numerous variations. The “T” intersection and four-leg intersection are the most prevalent in the lower-category streets. In addition, the use of roundabouts, which can accommodate all at-grade intersection configurations, has grown in popularity in recent years. A more detailed discussion of roundabouts can be found later in this chapter.

“T” Intersections

The “T” intersection, or three-leg intersection, consists of three approaches. This intersection normally has an automatic vehicular right-of-way assignment; however, some situations may warrant the elimination of this automatic right-of-way assignment. One situation is to control speed through a particularly straight section of the road. The “T” intersection has the least number of conflict points of any of the various types of intersections and therefore provides a high level of safety. Figure 20.24 illustrates some of the basic “T” intersection variations.

The intersection shown in Figure 20.24*a* is the most common in residential land developments where minor or local roads are prevalent and may be used when minor roads intersect important highways with an intersection angle less than 30° from normal. At locations with higher speeds and turning volumes, which increase the potential for rear-end collisions between through vehicles and turning vehicles, an additional area of surfacing or flaring should be provided, as shown in Figure 20.24*b*. In cases where left-turn volume from the through road onto the minor road is sufficiently high but does not require a separate left-turn lane, an auxiliary lane may be provided, as shown in Figure 20.24*c*. This provides the space needed for through vehicles to maneuver around the left-turning vehicles, which must slow down before making their turns. Figure 20.24*d* shows the addition of auxiliary lanes on each side of the through highway approaching the intersection. This type of intersection is suitable for locations where turn volumes onto the minor road are high, from both directions of the through road. An intersection of this type will generally be signalized.

Four-Leg Intersections

The four-leg intersection may or may not have an automatic right-of-way assignment. Depending on the design volume of traffic at the intersection, control can be as simple as yield/stop at the lesser-category street to signal control with auxiliary lanes and islands to channel the turning movements. Variations of the latter situation typically occur at intersections of major roads, such as collectors with minor arterials. Such intersections frequently are necessary at the fringe of large development projects in high-density areas. Figure 20.25 illustrates some of the basic configurations and various levels of the four-leg intersection.

The unchannelized intersection shown in Figure 20.25*a* is used mainly at locations where minor or local roads cross, although it can also be used where a minor road crosses a major arterial or collector road. In these cases the turning volumes are usually low and the roads intersect at an angle that is not greater than 30° from normal.

When turning movements are more frequent, a flared intersection with additional capacity for through and turning movements, such as those in Figure 20.25*b,* can be provided. The layout shown in Figure 20.25*c* shows a flared intersection with a marked pavement area that divides traffic approaching the intersection and is suitable for a two-lane highway that is not a minor crossroad, where speeds are high, intersections are infrequent, and the left-turning movements from the highway may create a conflict.

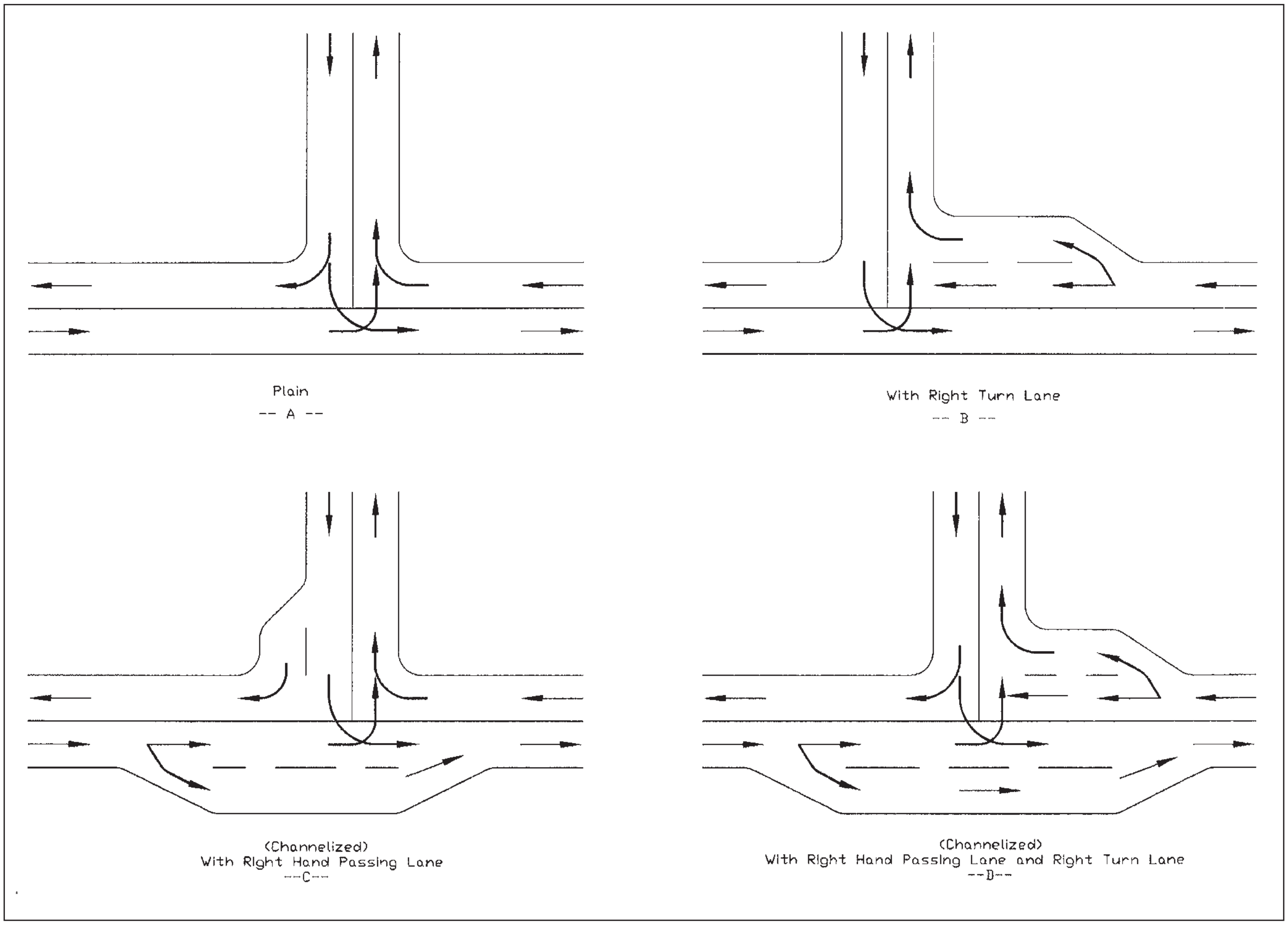

Figure 20.24 Types of "T" intersections. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

Figure 20.25*d* shows a channelized four-leg intersection with right-turning roadways in all four quadrants. This configuration is suitable in developments where turning volumes are high and pedestrians are present. The configuration presented in Figures 20.25*b* and *c,* where additional lanes are provided for left-turning movements, can be adopted for channelized intersections as well.

Figure 20.25*e* demonstrates a simple intersection with divisional islands on the crossroads. This configuration accommodates a large range of traffic volumes.

The layout shown in Figure 20.25*f* is suitable for a two-lane highway that is not a minor crossroad and that carries moderate volumes at high speeds or operates near capacity. Complete solutions and variations for various circumstances are numerous.

Multileg Intersections

Multileg intersections (those with five or more approaches) should be avoided wherever practical in land development. At locations where multileg intersections are used, it may be satisfactory to have all intersection legs intersect at a common paved area, where volumes are light and stop control is used. At other than minor intersections, traffic operational efficiency can often be improved by reconfiguration that removes some conflicting movements from the major intersection. Such reconfigurations are accomplished by realigning one or more of the intersecting legs and combining some of the traffic movements at adjacent subsidiary intersections, or in some cases by converting one or more legs to one-way operation away from the intersection. The distances between the newly formed intersections should be such that they can operate independently.

Angle of Approach

Right-angle intersections provide a better view of traffic and better turning movements than roads intersecting at acute angles. A recommended practice is to limit the angle of approach of the intersecting road to 60° (relative to the through street). In those situations involving intersections of legs at acute angles, the engineer should consider slight changes to provide a configuration closer to the desired 90° alignment.

Figure 20.26 shows how an approach street with an acute angle of approach can be modified to obtain a 90° intersection. On local roads, such an alignment is acceptable. On higher-category streets, this type of alignment should be used

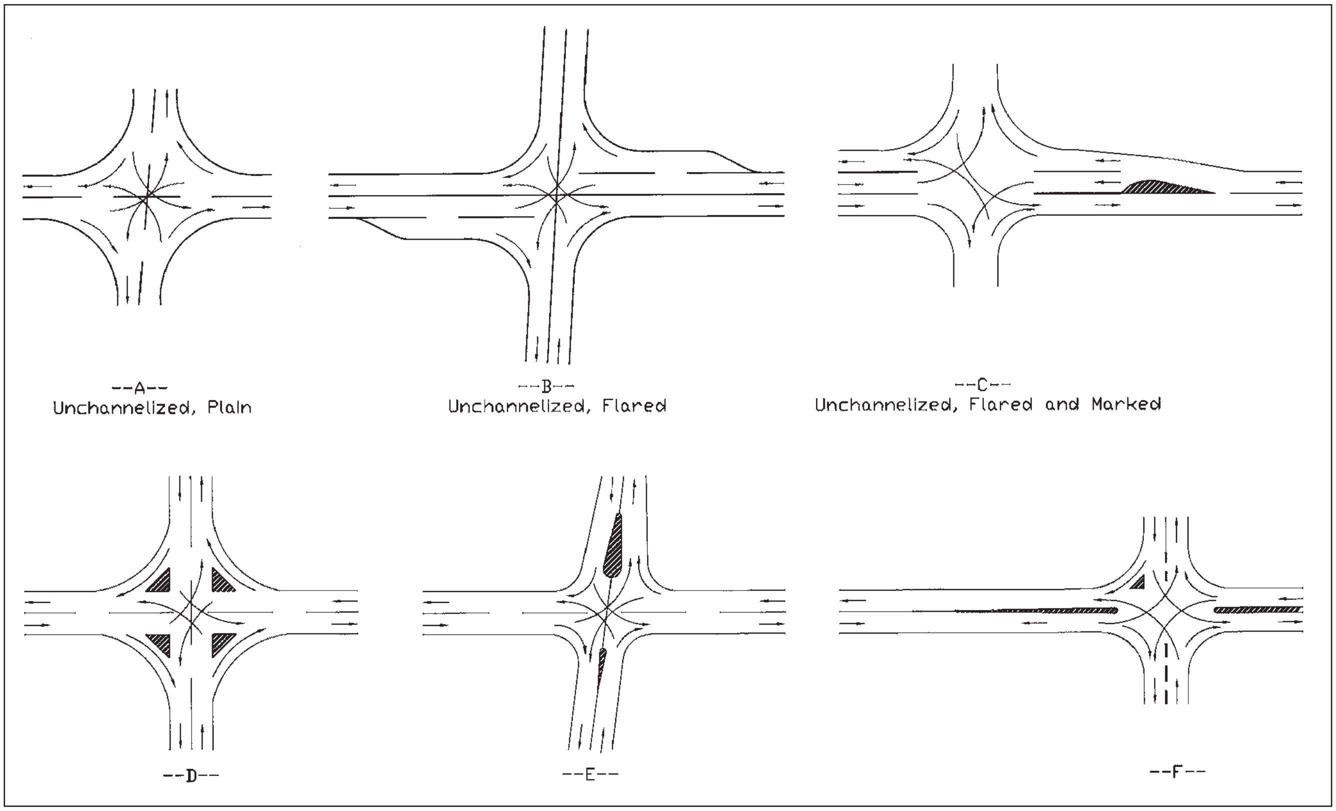

FIGURE 20.25 General types of four-leg intersections. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

cautiously. Although this type of alignment may improve visibility and turning movements, there are disadvantages to it. Traffic control devices are obscured, and vehicles approaching the intersection through the short radius curve tend to encroach into the opposite lane, creating a traffic hazard for vehicles turning from the main road.

Within a relatively large project, adjusting lot lines and street configurations can achieve proper alignment of intersections. For those projects that must access near or at an existing intersection, local agencies may require extensive modifications of the intersection to accommodate the additional volume of traffic. This can be costly and should be identified early in the project planning.

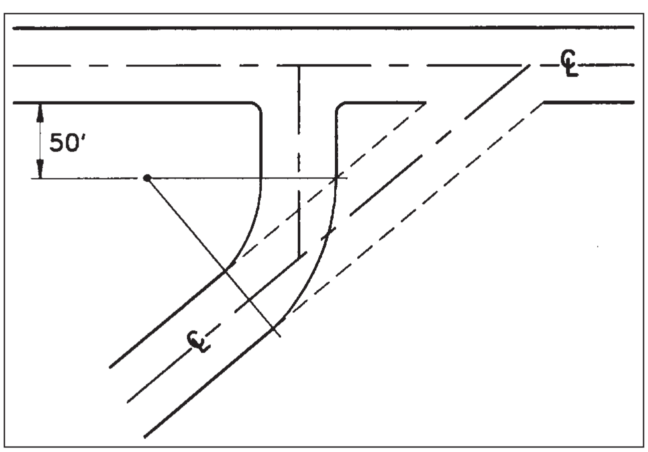

FIGURE 20.26 Realignment of intersecting road to obtain 90° configuration.

Intersection Sight Distance

Intersection sight distance for an at-grade intersection is subject to the type of traffic control at the intersection or, where no traffic control devices are present, by the rules of the road. At an intersection where no traffic control devices are present, a basic rule of the road would require the vehicle on the left to yield to the vehicle on the right if they arrive at approximately the same time. Sight distance is provided at intersections to let drivers identify the presence of potentially conflicting vehicles and to be able to stop or adjust their speed, as appropriate, to avoid intersection collision. The driver of a vehicle approaching an intersection should have an unobstructed view of the entire intersection, including any traffic control devices, and sufficient lengths along the highway to permit the driver to anticipate and avoid potential collisions. To enhance traffic operations, intersection sight distances that exceed stopping sight distances are desirable along the major road.

Clear sight triangles are specified areas along intersection approach legs and across their included corners that should be kept clear of obstructions that might block a driver's view of potential conflicts. The dimensions of the legs of the sight triangles depend on the design speeds of the intersecting roadways and the type of traffic control used at the intersection. These dimensions are based on observed driver behavior and are documented in NCHRP Report 383, *Intersection Sight Distance.* Two types of clear sight triangles are considered in intersection design: approach sight triangles and departure sight triangles, as illustrated in Figure 20.27.

Figure 20.27*a* shows typical clear sight triangles to the left and to the right for a vehicle approaching an uncontrolled or yield-controlled intersection. The vertex of the sight triangle on a minor-road approach (or an uncontrolled approach) represents the decision point for the minor road driver, where braking to stop should begin if another vehicle is present on an intersecting approach. The distance from the major road, along the minor road, is illustrated by the dimension *a* in Figure 20.27*a*. The geometry of a clear sight triangle is such that when the driver of a vehicle without the right-of-way sees a vehicle that has

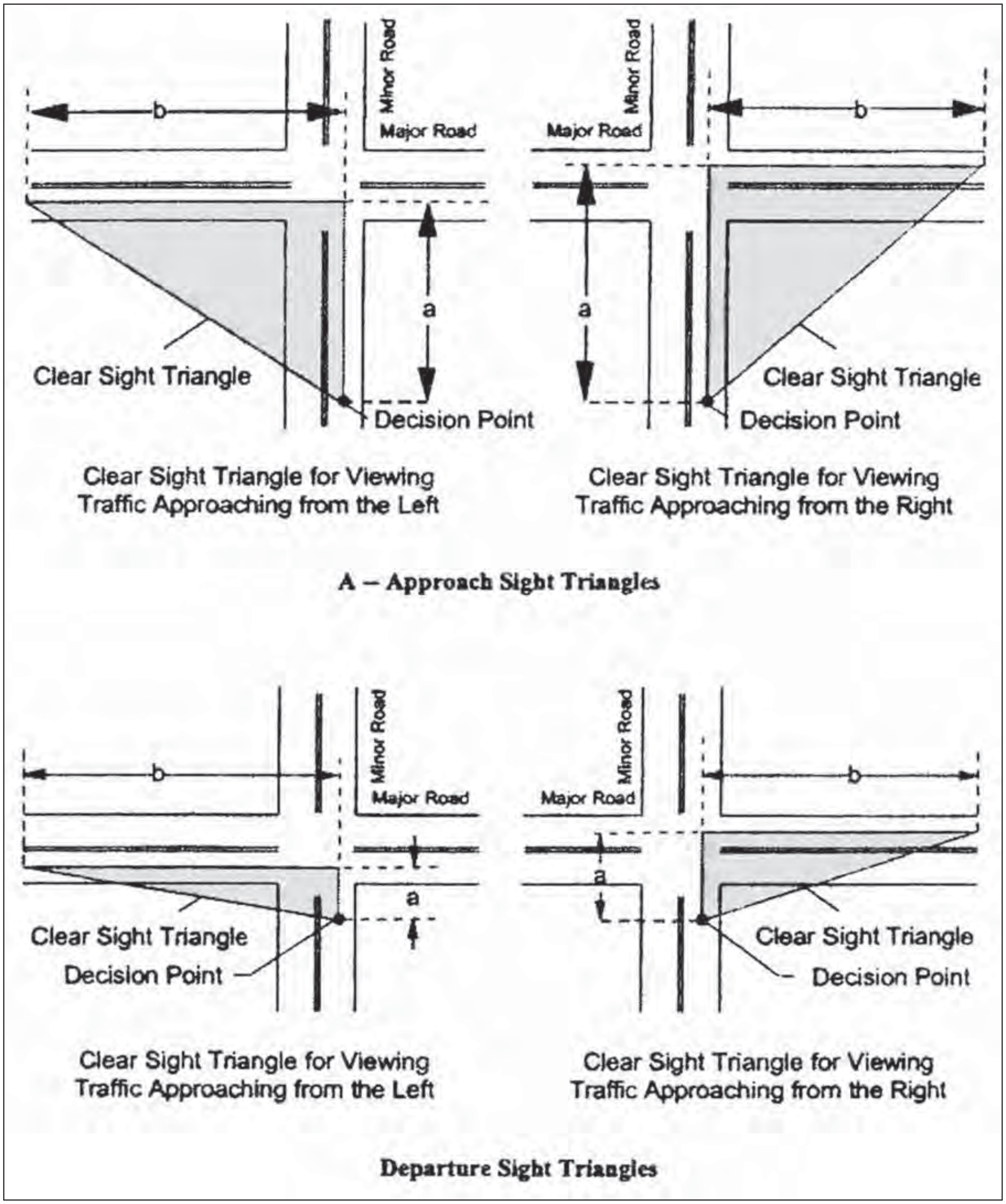

Figure 20.27 Intersection sight triangles. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

the right-of-way on an intersecting approach, the driver of that potentially conflicting vehicle can also see the first vehicle. Being the distance *b* away from the intersection, the driver of the vehicle with the right-of-way should be able to slow, stop, or avoid other vehicles, if it becomes necessary.

Figure 20.27*b* illustrates departure sight triangles necessary for a stopped driver on a minor road approach to enter or cross the major road.

For many land development projects, the most typical type of traffic control is the stop control. The vehicle on the minor street is required to completely stop, ensure that movement through the intersection, either entering the intersecting road or crossing it, can be safely done without colliding with oncoming traffic, and then proceed.

The driver on the minor road must have an unobstructed view for a sufficient distance in order to ensure that movement through the intersection can be safely accomplished. This sufficient sight distance depends on the speed of the oncoming vehicles and some nominal perception-reaction time representative of most drivers as well as the physical conditions of the intersection. The three types of movements for the stopped vehicle, the corresponding sight triangles, and the values of the related sight distances are explained in detail in AASHTO. These three basic cases are briefly elaborated upon here, while the detailed explanation of these and other cases (intersection with no control, intersections with yield control on the minor road, intersections with traffic signal control, intersections with all-way stop control) can be found in Chapter 9 of AASHTO.

1. *Crossing maneuver from the minor road:* The vehicle can proceed through the intersection, continuing along the minor street (four-legged intersections only). This requires that the vehicle clear traffic approaching from either direction of the major street and also vehicles turning left from the opposite direction on the minor street.

2. *Left turn from the minor road:* The stopped vehicle can turn left onto the major street, which again requires clearing traffic from both directions.

3. *Right turn from the minor road:* The stopped vehicle can turn right, which requires clearing traffic coming from the driver's left.

The vertex (decision point) of the departure sight triangle on the minor road and the corresponding assumed location of the driver's eye should be 14.5 feet from the edge of the major road traveled way. According to AASHTO, this assumed location of the driver's eye is 3.5 feet above the roadway surface, and the object to be seen is 3.5 feet above the surface of the intersecting road. In addition to AASHTO, the reader is referred to local highway design criteria to establish the intersection sight distances. Without the benefit of a specific method, a reasonable rule of thumb applicable to local-local and local-collector intersections is to allow 10 feet of distance for every 1 mph of design speed. For example, an intersection where the design speed of the major street is 35 mph requires a sight distance of 350 feet.

The preceding discussions on sight distance for at-grade intersections assume that grades on approach legs are almost level. When the grade along the intersection approach exceeds 3 percent, the leg of the clear sight triangle along the approach should be modified by multiplying the calculated sight distance by the appropriate adjustment factor. Both sets of data are clearly provided in table format in AASHTO. The same publication also prescribes the height of eye and the height of object at 3.5 feet; therefore, nothing in the line of sight, such as fences and vegetation, should be higher than this value.

Spacing

The type of intersection control influences the spacing of intersections. For example, several consecutive intersections with signal control where synchronization is necessary will be spaced farther than stop/yield control intersections in a residential area. On local streets in residential areas, recommended minimum spacing is 125 feet. On collector streets, spacing should be increased to 250 feet.

In commercial areas, frequently there are numerous entrances to the office and retail areas accessing the main street. Although these are not intersections as defined earlier, the volume of traffic and the numerous turning movements require these entrances to be treated as intersections. Residential driveways are not considered intersections because of the low volume and few consecutive turning movements. Recommended spacing of commercial entrances is also around 200 feet, depending on the traffic on the serving road and the anticipated traffic through each entrance. Spacing may be reduced if the turning movements into and out of the entrances are limited to the direction of flow of traffic, in other words, right-in and right-out movements.

Intersection spacing is always a matter for consideration in maintaining safe streets and avoiding traffic queuing. Excessive queuing is not a critical design element on low-volume streets. In most cases, intersection spacing of 125 feet eliminates traffic flow problems. Such spacing also prevents corner cutting from one street to another.

Curb Return Radius

The ability of a vehicle to turn safely and effectively depends on such factors as type of vehicle, pavement width, curb return radius, speed through the turn, longitudinal and transverse pavement slope, and skew angle of the intersection. Ideally, as the vehicle makes a turning movement, it remains within the limits of the designated lane. On local streets, for which the design vehicle is predominantly small and the design speeds and traffic volumes are low, whether the vehicle stays within the confines of the designated travel lane is of minor consequence. The radius of curvature of the curb return affects the width of the entrance of the street. Since pedestrian safety is paramount in residential areas and speeding is discouraged, short radius curb returns are more desirable.

In commercial and industrial developments, pavement widths and curb returns are matched to accommodate larger vehicles and reduce (or eliminate) the need for the vehicle to encroach into other lanes during the turning movement. However, as the curb return radius increases, the entrance width increases, and consequently lane designations through the intersection are obscured. The need for channelization by islands or special pavement markings to delineate the travel lanes then becomes a consideration.

According to the ASCE/NAHB/ULI's *Residential Street Design,* (3rd ed., 2001), the recommended range for curb return radii is 10 to 15 feet at local-local street intersections, 15 to 20 feet at local-collector intersections, and 15 to 25 feet at collector-collector intersections. However, most jurisdictions prescribe minimum radius of curvature for the curb returns. The engineer should use discretion in setting these radii. The curvature is based on the largest type of vehicle that will frequently use the street, pedestrian safety, and the cost for maintenance of the right-of-way and the loss of usable land for development.

When determining the curb return radii, consideration must be given for the largest vehicles that will use the street. Although large vehicles such as moving vans, motor homes, and buses only occasionally traverse local streets and would not be selected as the design vehicle, consideration should be given to allow for their limited use. Accomplish this by checking larger vehicle requirements regarding turning and clearance. The use of transparent vehicle templates made to the same scale as the site plan or computer software such as AUTOTURN that simulates vehicle turning movements assist in checking these provisions. An example of one template is shown in Figure 20.28. Other templates for the vehicles listed in Table 20.3 are provided in the AASHTO manual.

The minimum turning radii values for twenty different vehicle types are listed in Table 20.3.

Profile Grade Line (PGL) at Intersections

Proper alignment of street profiles at intersections provides a smooth transition through the intersection. The profile requirements of the intersecting side street vary significantly depending on the type of intersection control, that is, whether the intersection is signalized or has a stop sign, and, to a lesser extent, the design speed of the side street and whether it's a three-leg or four-leg type of intersection. If signalized, a portion of the traffic will arrive on the green indication and continue through the intersection without significantly slowing down. In this case, the design speed through the intersection will impact the profile design. With stop sign conditions, the design speed is negligible for the PGL design.

Ideally, the longitudinal approach grade of the intersecting street should be the same as the cross slope of the through street. However, this is rarely accomplished, due to a mismatch of the main roadway cross slope with the site and design constraints that may impact the approach grade of the side street. Some means is necessary to provide smooth transition between the PGL of the side street with the cross slope of the through street. For practical considerations, there are three basic methods in establishing the profile grade line for the intersecting street, as illustrated in Figure 20.29. The design standards for the review agency dictate which method, if any, and the acceptable values permitted.

Figure 20.29*a* shows the transition as just a grade break, that is, the algebraic difference of the grades. This method is typically used for stop conditions and extremely slow speeds through the intersection. This also includes the speeds of the vehicles turning from the through street onto the side street. An algebraic difference of about 4 percent to 5 percent may be permitted. Higher values of the grade break have been used; however, the bouncing effects of the car over the grade break could cause riding discomfort and cause the underside of some vehicles to scrape the pavement.

As shown in Figure 20.29*b,* a short vertical curve of 50 to 100 feet provides a smoother transition when the grade break becomes too large. For slow speeds through the intersection, the vertical curve sight distance as dictated by Equations 20.14 and 20.15 is negligible.

Figure 20.29*c* provides the best way to connect the two PGLs for the combined conditions of higher design speeds of the side street, for signalized control, and for grades with large algebraic differences. A section of nearly level roadway at the side street provides a staging area for stopped vehicles, improves sight distance, and allows the stopped vehicles to begin their movement without drifting backward or having to hold the brake pedal too stiffly to keep the vehicle from rolling during the red indication. Additionally, this method, with appropriate vertical curves, provides a smoother ride through a four-leg intersection. Although not specifically addressed in most design manuals, the length of the staging section should be based on intersection conditions, good engineering judgment, and, possibly, stopping distance for the design speed. Finally, note that as a minimum, the tangent point of the vertical curve should be located outside the edge of pavement (EP) of the through street.

Matching the PGL alignment becomes more difficult when a superelevated through street must be matched to a side street with a longitudinal slope in the opposite direction. Factors such as sight distance, design speed, tangent gradients, intersection control, and other items must be considered to determine a safe and cost-effective design. Frequently, a short vertical curve connecting the two opposing slopes does not allow for sufficient sight distance or does not provide a suitable landing area. Use of a longer vertical curve may require extensive grading.

The situation becomes more complex for skewed intersections, or if the intersecting street is on a curve that connects to a through street in superelevation or transition. For this reason, 90° intersections are strongly recommended to reduce the design complications associated with these situations. Furthermore, review agencies are less receptive to such irregular designs.

Another recurring problem in intersection design is matching the curb returns, especially when the radius is very large and the arc length is long. It is not uncommon for the

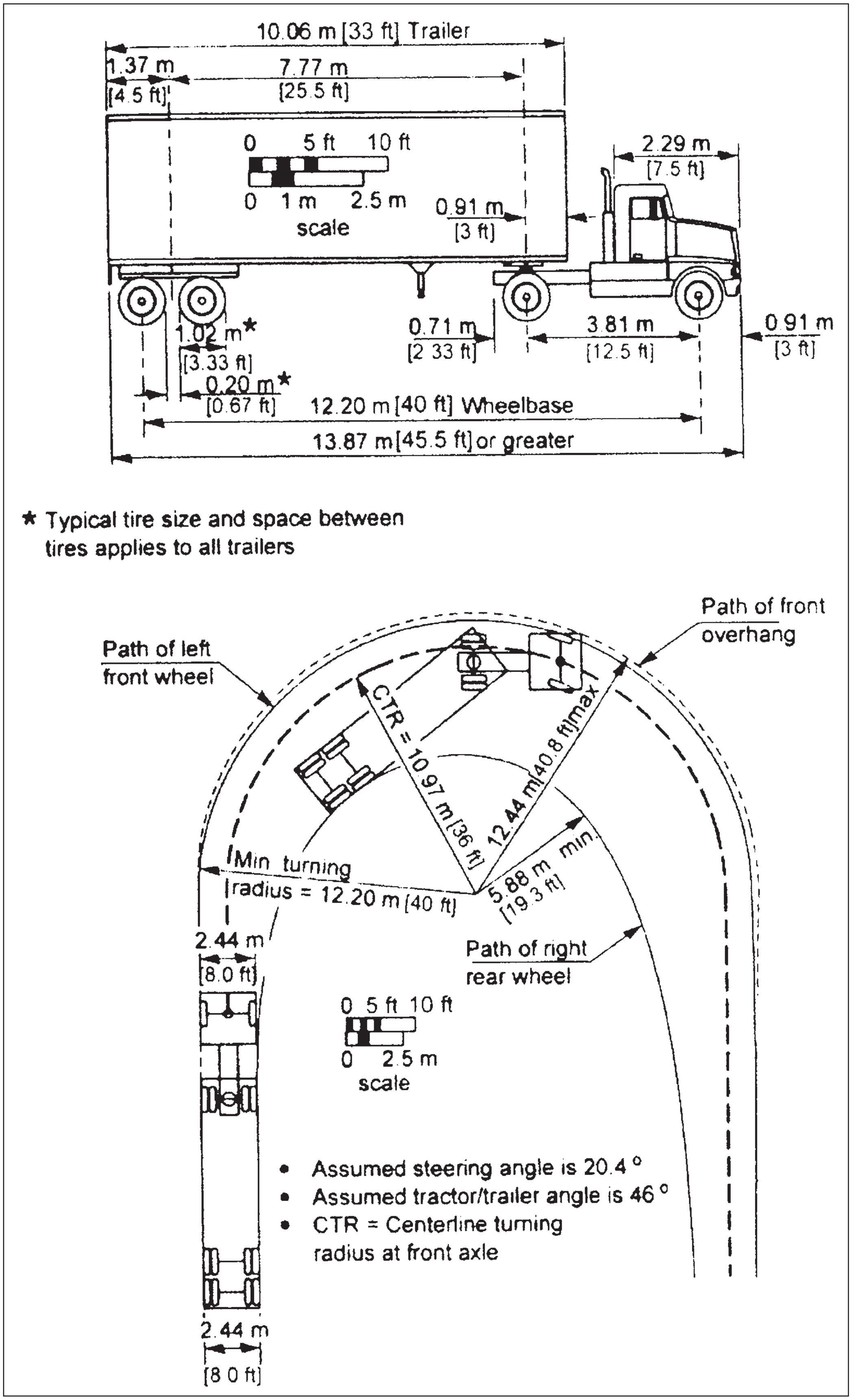

FIGURE 20.28 Minimum turning path for WB-40 design vehicle. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

TABLE 20.3 Minimum Turning Radii of Design Vehicles

Design Vehicle Type	Passenger Car	Single-Unit Truck	Intercity Bus (Motor Coach)		City Transit Bus	Conventional School Bus (65 pass.)	Large[2] School Bus (84 pass.)	Articulated Bus	Intermediate Semitrailer	Intermediate Semitrailer
Symbol	**P**	**SU**	**BUS-40**	**BUS-45**	**CITY-BUS**	**S-BUS36**	**S-BUS40**	**A-BUS**	**WB-40**	**WB-50**
Minimum Design Turning Radius (ft)	24	42	45	45	42.0	38.9	39.4	39.8	40	45
Centerline[1] Turning Radius (CTR) (ft)	21	38	40.8	40.8	37.8	34.9	35.4	35.5	36	41
Minimum Inside Radius (ft)	14.4	28.3	27.6	25.5	24.5	23.8	25.4	21.3	19.3	17.0

Design Vehicle Type	Interstate Semitrailer		"Double Bottom" Combination	Triple Semitrailer/ trailers	Turnpike Double Semitrailer/ trailer	Motor Home	Car and Camper Trailer	Car and Boat Trailer	Motor Home and Boat Trailer	Farm[3] Tractor w/One Wagon
Symbol	**WB-62***	**WB-65** or WB-67**	**WB-67D**	**WB-100T**	**WB-109D***	**MH**	**P/T**	**P/B**	**MH/B**	**TR/W**
Minimum Design Turning Radius (ft)	45	45	45	45	60	40	33	24	50	18
Centerline[1] Turning Radius (CTR) (ft)	41	41	41	41	56	36	30	21	46	14
Minimum Inside Radius (ft)	7.9	4.4	19.3	9.9	14.9	25.9	17.4	8.0	35.1	10.5

*Design vehicle with 48-ft trailer as adopted in 1982 Surface Transportation Assistance Act (STAA).
**Design vehicle with 53-ft trailer as grandfathered in with 1982 Surface Transportation Assistance Act (STAA).
[1]The turning radius assumed by a designer when investigating possible turning paths and is set at the centerline of the front axle of a vehicle. If the minimum turning path is assumed, the CTR approximately equals the minimum design turning radius minus one-half the front width of the vehicle.
[2]School buses are manufactured from 42-passenger to 84-passenger sizes. This corresponds to wheelbase lengths of 11.0 ft to 20.0 ft, respectively. For these different sizes, the minimum design turning radii vary from 28.8 ft to 39.4 ft and the minimum inside radii vary from 14.0 ft to 25.4 ft.
[3]Turning radius is for 150–200 hp tractor with one 18.5-ft-long wagon attached to hitch point. Front wheel drive is disengaged and without brakes being applied.
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contractor to have to warp the pavement at the intersections to match pavements and slopes. For the most part, a good alignment design minimizes the amount of warping done in the field to accommodate matching pavements.

It is good design practice in such situations to plot the profiles of the curb returns. This helps in setting stakeout grade for construction, ensures positive drainage around the return, and permits a smooth continuous curb return. Selecting a mathematical vertical curve to the curb return profile is desirable, but for the cases where a true mathematical fit cannot be accomplished, the designer draws a smooth curve using a parabolic template or best-fit curve in CAD applications such as AutoCAD or Microstation. This is commonly known as a spline curve. The curb return elevations are scaled directly from the smoothly drafted spline and shown on the plans.

Channelization

Wide street entrances at intersections, such as those generated by large curb return radii or skewed intersecting streets, create large areas of pavement that confuse drivers and promote irregular vehicle movements. To mitigate these conditional hazards, painted pavement markings or raised islands are installed to direct the traffic flow. Raised islands also serve as pedestrian refuge points, separate opposing traffic, and serve as attractive aesthetic focal areas for the development when landscaped. In the latter case, however, the landscaping must not impede sight distances nor obstruct the driver's view of pedestrians.

The size, configuration, and method of channelization are very site specific. Factors to consider include the volume of traffic, the type of intersection control, the geometry of the intersecting streets, and, most important, the requirements and standards of the approving public agencies.

The islands must be large enough to be visible to drivers for each turning movement affected by the island. AASHTO recommends the island area to be not less than 50 square feet as an absolute minimum and preferably 100 square feet in size. Triangular islands should be 12 feet long on a side, not including the rounding at the corners. Raised curb islands are set 2 to 4 feet from the edge of pavement of the through street on low-speed roads. The setback increases with increasing design speed on the through street (see Figure 20.30).

Crest and Sag Vertical Curves with Respect to Intersections

Intersection location on vertical curves must meet sight distance requirements. This is more critical on crest curves than on sag curves due to the more restricted limits inherent in

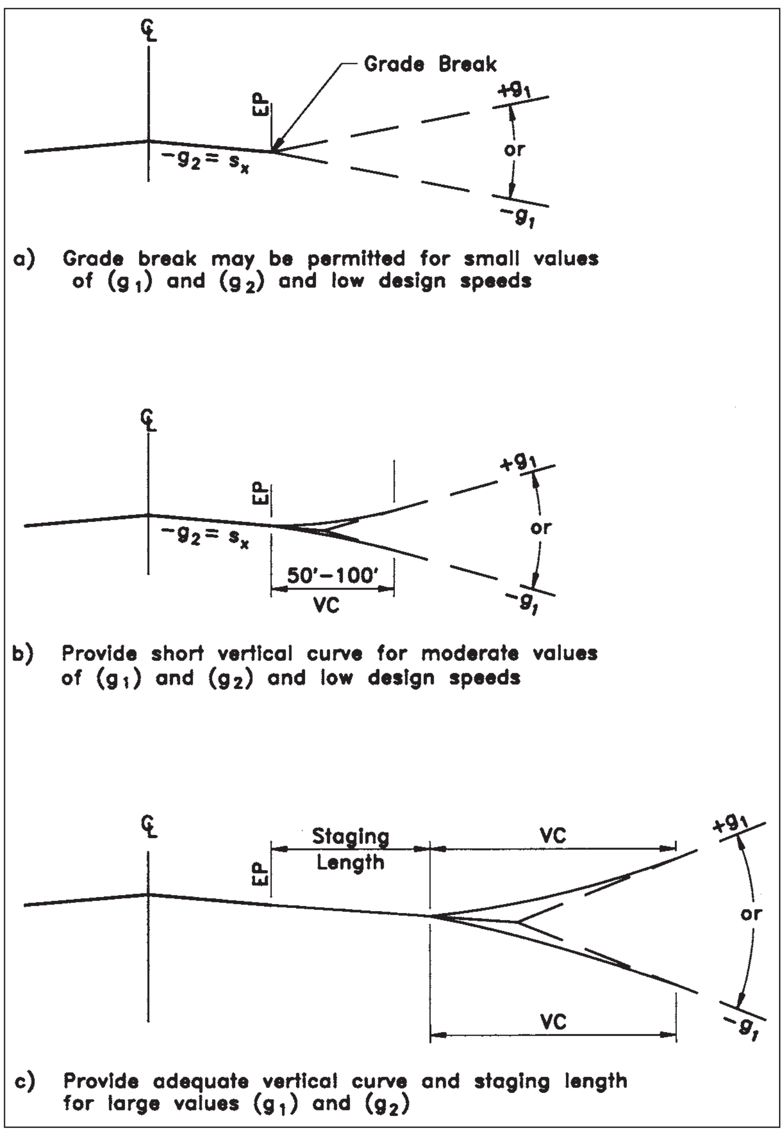
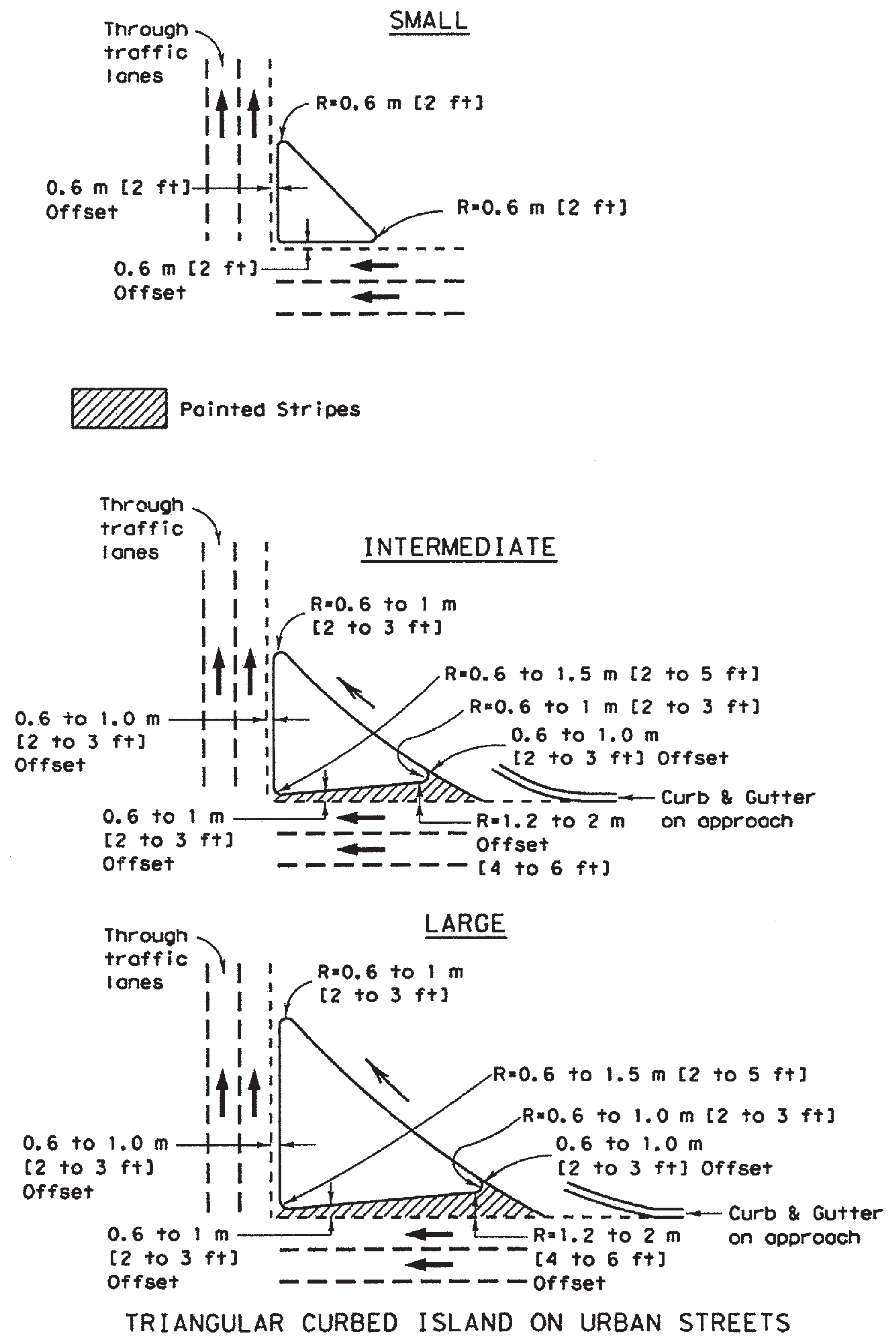
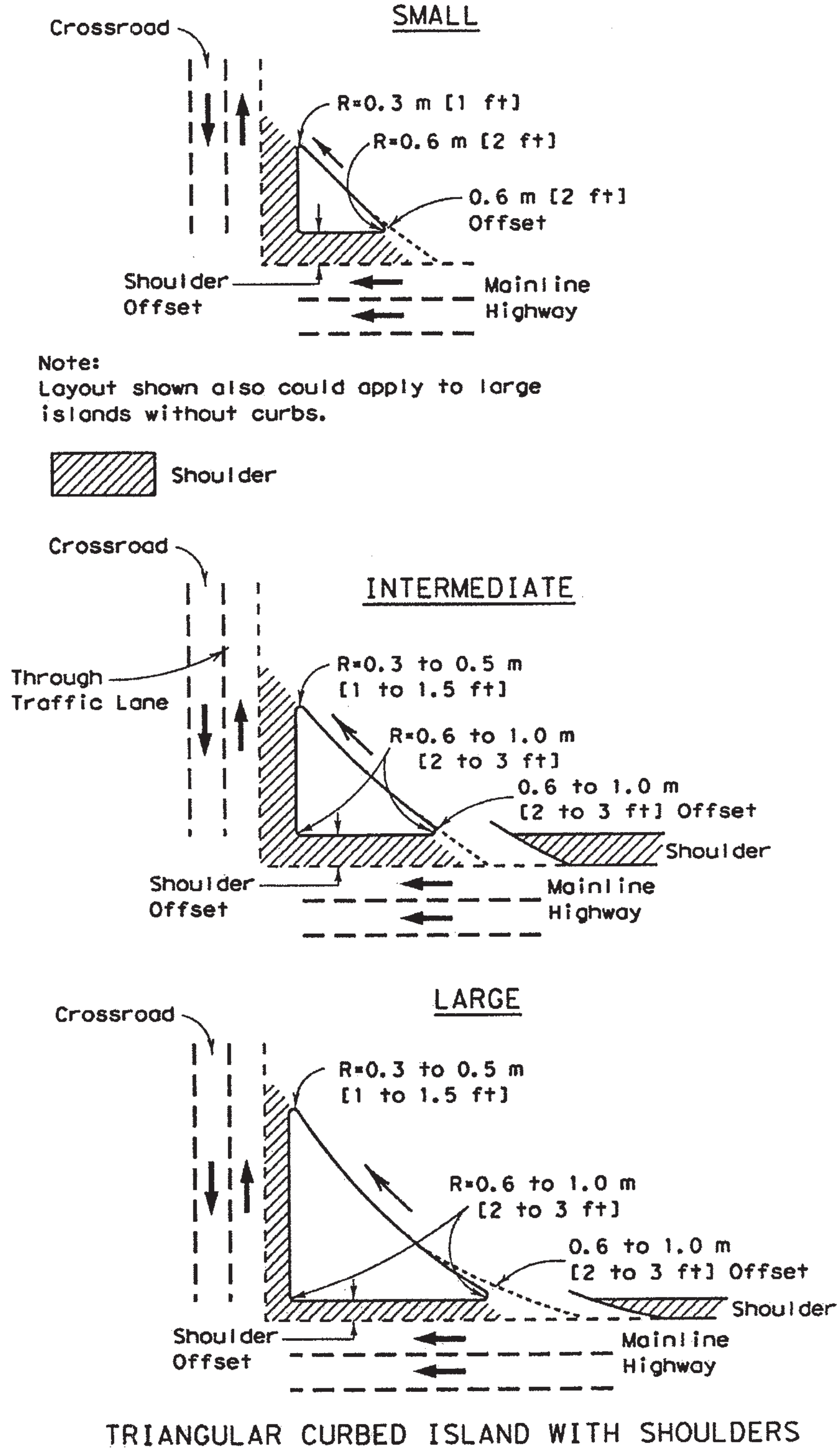


FIGURE 20.29 PGL for connecting streets.



Details of Corner Island Designs for Turning Roadways (Urban Location)

FIGURE 20.30 Details of corner island designs for turning roadways: (*a*) urban location; (*b*) rural location. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the Washington, DC: American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)



Details of Corner Island Designs for Turning Roadways (Rural Cross Section on Approach)

FIGURE 20.30 (*Continued*)

crest curves. Intersection sight distance is generally 10 times the design speed (or greater). On short vertical curves with relatively steep tangent grades, the optimum location is at or very near the top of the crest. As the length of the crest curve increases and the grades flatten, the intersecting street can be located farther away from the crest.

On sag curves, sight distance is secondary to drainage as a design consideration. Because of the potential drainage problems, the intersecting street should not be located at or very near the sump area of a sag curve. The location of the intersecting street depends on the length of the vertical curve and the tangent gradients.

Bicycles at Intersections

When on-street bicycle lanes and/or off-street bicycle paths are present in the land development, the design of the intersections in the development should be modified to reflect the presence of these facilities.

The following measures can be introduced:

- Special sight distance considerations
- Wider roadways to accommodate on-street bicycle lanes
- Special lane markings to channelize and separate bicycles from right-turning vehicles
- Provisions for left-turn bicycle movements
- Special traffic signal designs (such as conveniently located push buttons at actuated signals or even separate signal indications for bicyclists)

The subject of bicycle facilities is further treated in this chapter under "Bicyclists" and in the AASHTO *Guide for the Development of Bicycle Facilities.*

Street Layout

Considering the numerous issues that are factored into street design, the street layout, like any design process, is iterative. Not all of the issues can be addressed, nor are all solutions apparent on the first try. Following is a general procedure for street layout using a hard-copy approach (similar tasks can be performed by computer, using land development software).

1. Obtain an appropriate scale of the plan view of the project showing topography and all existing features. The scale and contour interval depend on the size of the project and the availability of existing topographic maps. For large projects (e.g., >100 acres), 1 inch = 100 feet and 5-foot contour intervals are acceptable for preliminary layouts. The scale of the plan view increases as the size of the project decreases. (It is very difficult to use a worksheet at 100 scale if the site is only a few acres.)

2. On the drawing worksheet, identify the site constraints and locate the points of access to the existing road network, taking into consideration sight distances and proximity to existing intersections. Local ordinances may require that sections of the proposed road be extended to the boundaries of the site to provide future access to adjacent parcels.

3. Set the horizontal alignment of the street network of the site by drawing straight lines. These lines represent the centerline tangents of the proposed roads. To minimize grading, the tangents should run closer to parallel with the existing contours rather than perpendicular.

4. After the tangents have been established and comply with the physical constraints of the site, horizontal curves are drawn. The radius of the curves must comply with the given criteria regarding curvature, design speed, design vehicle, and street category.

5. Prepare a profile view of the existing topography of the PGL for the road and include all vertical constraints such as culvert and utility crossings. With a profile of the existing ground elevation, draw a series of straight lines that represent the proposed longitudinal grade of the street. The maximum and minimum gradients selected should comply with local requirements.

6. Select vertical curves to meet sight distance and drainage constraints. Set the vertical curves on the profiles using appropriate curve length with the required vertical curve sight distance. Label the stations of the PVCs, PVTs, and high and low points. Show the length of the vertical curve and the *K* value (or SSD). See Figure 20.42 (notice the labeling of the horizontal sight distance at the street intersection) for an example. General guidelines for establishing vertical alignment include the following:

   □ Avoid long lengths of steep grades.

   □ Place steeper grades at the beginning of an ascent, followed by flatter grades at the peak.

   □ Reduce gradients at intersections.

7. Determine and depict the right-of-way widths of the streets as per local regulations. Using the zoning requirements (e.g., minimum lot size and widths), establish the lot lines. As the lot lines are set, the horizontal alignment may have to be adjusted to make the lot lines work.

8. Perform an earthwork computation. Adjust the street alignment to balance the earthwork.

9. Repeat as necessary to optimize the lot layout, the earthwork balances, and other constraints.

Finally, the designer must coordinate the horizontal and vertical alignments. Often they are designed independently, without consideration of the combined effects. When all specific criteria such as minimum radius of curvature, sight distance, optimizing land use, intersection alignment and configuration, and balancing earthworks, have been accommodated, the combined effects of the horizontal and vertical alignments need to be checked for compatibility.

One method to help visualize the complete picture is to develop the grading plan or, using a computer, a three-dimensional grading surface. In addition to showing how the horizontal and vertical curves are aligned, the grading plan or 3D surface shows the location of deep excavation and embankments and where and how the grading encroaches on the lots and adjacent properties. Another way to compare the horizontal with the vertical alignment is to set the profile sheet on a table or computer screen with the plan sheet such that the stationing of one sheet is aligned with the stationing of the other. This is most effective when the plan view scale matches the horizontal scale of the profile view. A common practice is to show the plan and profile views on one drawing sheet (see Figure 20.42).

Considerations for ensuring that the horizontal alignments are compatible with the vertical alignment are as follows:

- Flatten profiles at intersections to allow for better visibility and starting, stopping, and turning movements.
- Avoid a series of short vertical curves that give a roller-coaster effect regardless of the horizontal alignment.
- Avoid a sag vertical curve at the beginning or end of a sharp horizontal curve.
- Avoid short vertical curves through compound curve.
- Avoid a sharp horizontal curve at the bottom of a long grade (especially a steep grade).
- Avoid a crest vertical curve on a short tangent between two horizontal curves.
- Avoid a sharp horizontal curve near the top of a crest vertical curve.
- In general, roads aligned perpendicular to the contours will cause buildings to have one side extend farther out of the ground. This type of alignment can also create undesirable steep grades and extensive earthwork. Roads aligned parallel to the contours can cause buildings to be lower than the road if the road is located at the outer edges of the slope. This type of alignment typically requires less earthwork and does not create steep slopes.

Each site is unique and all of the preceding guidelines, in all likelihood, cannot always be implemented. Compromises will have to be made, and it is the design team's responsibility to devise a layout that is safe, aesthetically attractive, and economically viable, while optimizing land use.

Cul-de-sacs and Turnarounds

The cul-de-sac is a popular street type for use on local streets. Cul-de-sac streets are open at one end and provide a turning area at the closed end. Although the circular cul-de-sac and its variations may be the most widely used, other types of turning areas include "T" and "Y." Some of these are depicted in Figure 20.31. The "T" and "Y" type require more inconvenient backing movements by the user, but in low-volume situations they conserve land and allow increased flexibility in the land-planning process. The type chosen for a particular situation depends on the primary type of vehicle being serviced by the turning area, traffic volume, and, most important, the standards accepted by the approving agency.

Because they are open only at one end, cul-de-sacs are limited to an average daily traffic (ADT) volume of about 200 vehicles per day. If it is assumed that a single-family residence generates 10 trips per day, then 20 residences will generate an ADT of 200 vehicles. Lot widths range from about 65 feet for small lots to 100 feet for moderately sized lots. Based on these assumptions, the maximum length of a cul-de-sac street is generally 650 to 1000 feet.

The recommended radius for an all-paved cul-de-sac is 30 to 40 feet. Most passenger vehicles require a minimum radius of 30 feet to turn around. Small trucks and fire equipment can turn around with one or two backing movements on 40-foot-radius cul-de-sacs. However, this presumes no vehicles are parked within the turnaround area.

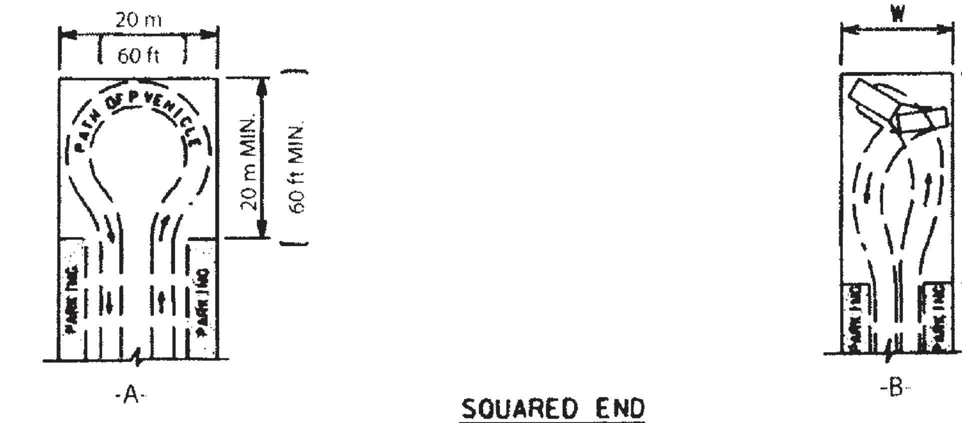
Other variations or shapes of cul-de-sacs may be provided to permit vehicles to turn around by backing only once. Several types (Figure 20.31*f*–*i*) may also be suitable for alleys, which provide access to the side or rear of individual land parcels.

For practical reasons, cul-de-sacs should be relatively level. Pavement grades across the cul-de-sac should ensure adequate drainage over the pavement and yet allow a vehicle to access adjacent land. A vehicle should be able to turn around without negotiating steep grades. Maximum pavement grades across the cul-de-sac of 3 percent to 4 percent are recommended. The street grade entering the cul-de-sac should be between 3 percent and 5 percent. To ensure proper design, the edge of pavement or top of curb around the perimeter of the cul-de-sac should be profiled. Spot elevations around the cul-de-sac based on the resulting profile aid the contractor in construction.

The lengths of the vertical curves and tangent grades should be selected to provide a relatively flat area around most of the perimeter of the cul-de-sac. This would allow for smoother driveway connections. Site conditions and drainage considerations are key factors in determining the lengths, locations, and tangent grades of curves. An example of a typical cul-de-sac plan and profile is shown in Figure 20.32.

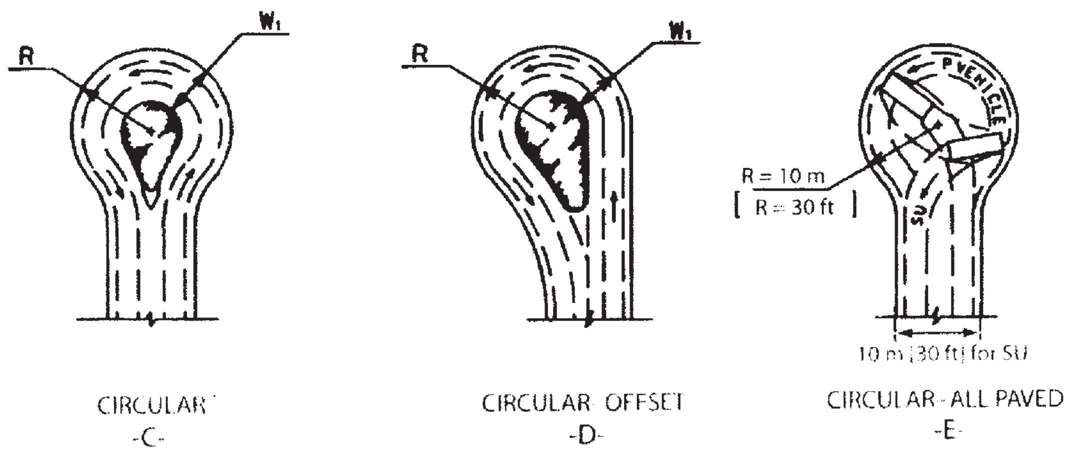
TRAFFIC CONTROL DEVICES

Traffic control devices (TCDs), such as signals, roadway signs, and pavement markings, are used to regulate, warn, and guide drivers. In theory, the rules for installing TCDs are relatively simple and are explained in the *Manual of Uniform Traffic Control Devices* (MUTCD; FHWA, 2003), the state laws and regulations, and local governing body (town, county,



SQUARED END

DESIGN VEHICLE	METRIC m		U.S. CUSTOMARY [ft]	
	W	L	W	L
P	10	20	[30]	[60]
SU	15	30	[50]	[100]



DESIGN VEHICLE	METRIC m		U.S. CUSTOMARY [ft]	
	R	W	R	W
P	10	6	[30]	[18]
WB-12 [WB-40]	13	8	[42]	[25]
SU & WB-15 [WB-50]	15	10	[47]	[30]

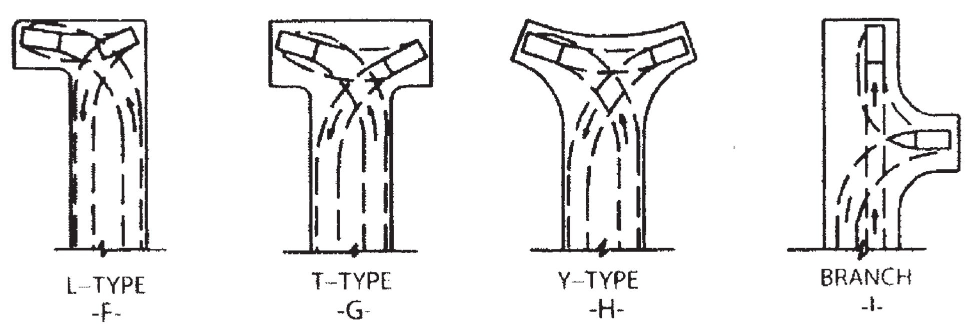


Figure 20.31 Types of cul-de-sacs and dead-end streets. (From *A Policy on Geometric Design of Highways and Streets,* 2004, by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission)

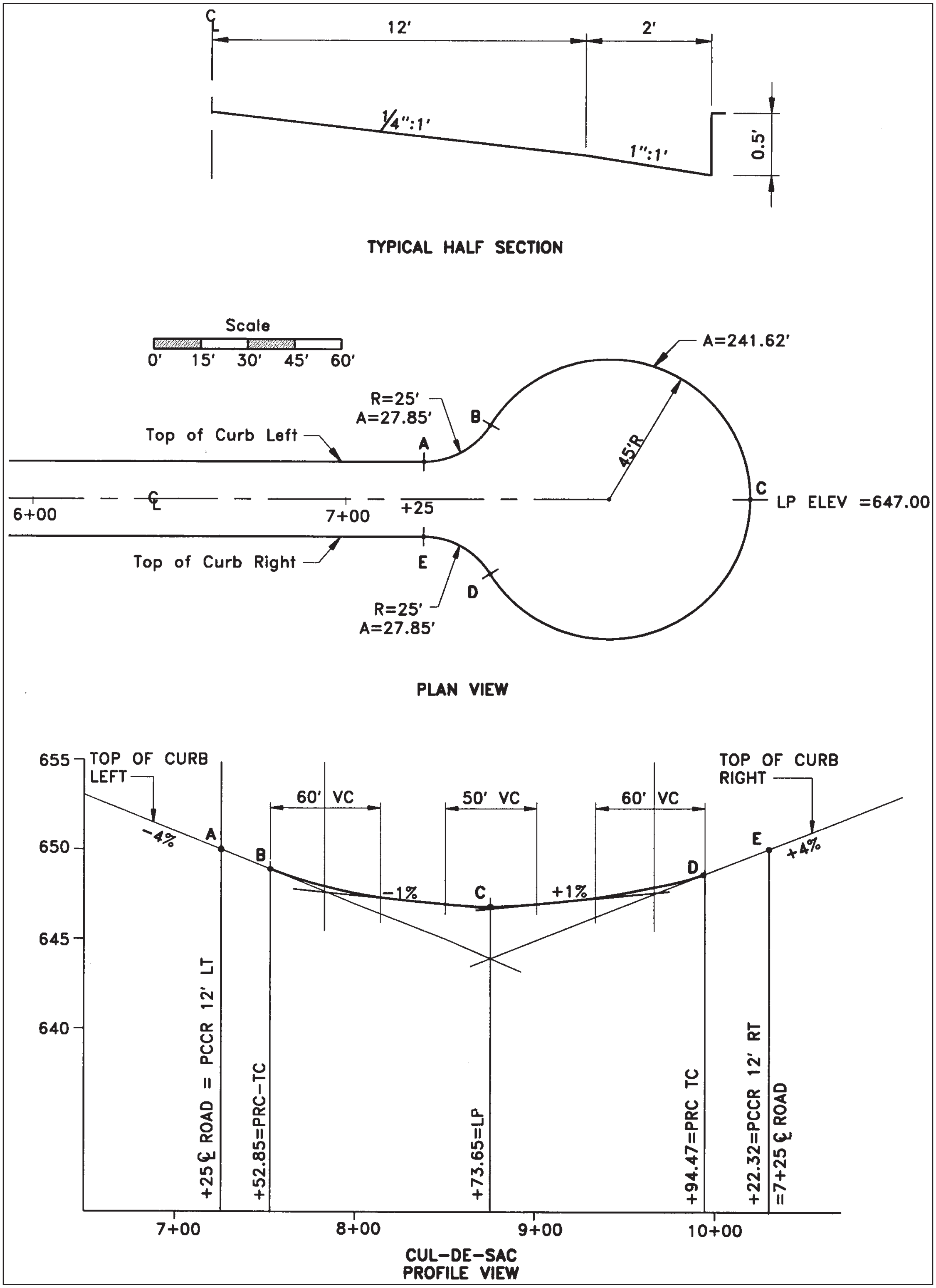


FIGURE 20.32 Cul-de-sac typical section, plan, and profile.

etc.) rules, regulations, and statutes. In practice, placing and maintaining TCDs requires diligence and good management practices to emphasize public safety.

An effective TCD should meet five basic requirements as follows:

1. It should be needed (based on warrant analysis, as covered in Chapters 5 and 19)
2. It should command attention.
3. It should convey a clear, simple message.
4. It should command respect.
5. It should be placed to get the proper response from the driver.

It is essential that intersection design be accomplished simultaneously with the development of signal, signing, and pavement marking plans to ensure that sufficient space is provided for proper installation of TCDs.

For further guidance on pavement markings and striping, in addition to the MUTCD, refer to NCHRP Report 356, *Pavement Markings—Design and Typical Layout Details.*

TRAFFIC CALMING

Traffic calming refers to any number of measures used to reduce the speed and/or volume of vehicles using a street or roadway network. It is defined by the ITE as "the combination of mainly physical measures that reduce the negative effects of motor vehicle use, alter driver behavior and improve conditions for non-motorized street users" (Lockwood, 1997, pp. 22–24). A large variety of measures are available for implementation, ranging from speed humps and tables to street closures. Many of these measures are intended for implementation on an existing street network to modify existing driver behavior and are frequently installed at the request of residents in response to what is perceived as unduly high volumes or speeds through a residential neighborhood. However, there are a number of measures that can be utilized in the design stage for a new subdivision to prevent the unwanted driver behavior in the first place. The following discussion focuses on such measures.

Traffic-calming measures are grouped into two primary categories: volume control measures and speed control measures. Speed control measures are further subdivided into vertical measures, horizontal measures, and narrowings. In addition, one significant traffic-calming measure is particularly effective as both a volume and speed control measure: the modern roundabout or community traffic circle.

Volume Control Measures

Volume control measures are those intended to limit the amount of through traffic utilizing the streets in a community. More so than speed control measures, most traditional volume control measures are intended as retrofit solutions intended to disrupt travel through an existing street grid. However, two of these measures do have analogous designs that could be implemented in the design of a grid pattern for new developments. The use of cul-de-sacs achieves the same effect as full road closures, creating a dead end; loop roads, however, are essentially equivalent to diagonal diverters, forcing drivers to circle back to the original street they turned in from. In addition, the construction of median barriers (Figure 20.33) through an intersection is an effective method of restricting through traffic.

Speed Control Measures

Speed control measures are those intended to reduce speeding through a neighborhood by using physical forces to induce drivers to slow down (vertical and horizontal measures) or by using a sense of confinement to inhibit speeding (narrowings).

Vertical Measures. There are essentially three different vertical traffic-calming measures that are utilized to control speeds. The two most common of these are the speed hump and the speed table (Figure 20.34). These are areas of pavement 3 to 4 inches high and 12 feet (speed hump) or 22 feet (speed table) long. While humps and tables are effective in reducing speeds, there are concerns regarding their installation, particularly pertaining to emergency vehicle access; additional noise due to vehicle acceleration, braking, and the jarring effect, particularly of humps; and the potential for accidents if a driver approaches the hump or table at too great a speed and loses control of the vehicle. For these reasons, these measures are not recommended for use in new street development.

The third vertical measure is the raised intersection, where an entire intersection is raised several inches above the elevation of the approaching streets, usually to the level

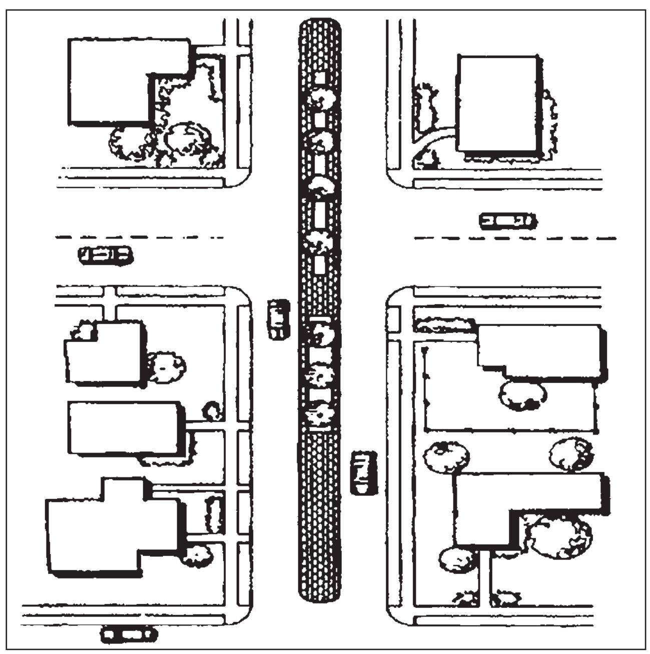


FIGURE 20.33 Median barrier. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

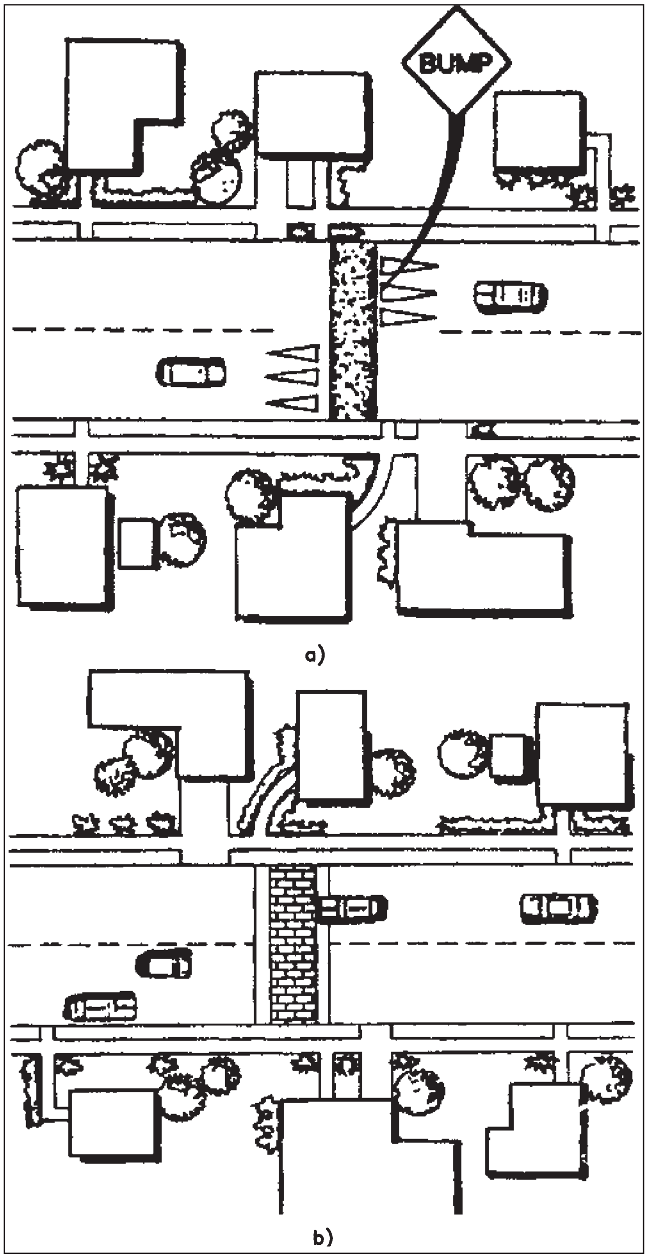


FIGURE 20.34 (*a*) Speed hump and (*b*) speed table. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

of the sidewalks at the corners (Figure 20.35). Raised intersections are effective at slowing traffic on all intersection approaches, thereby making the intersection more pedestrian friendly, although their effect on midblock speeds is much less pronounced.

Horizontal Measures. There are several horizontal speed control measures that can be easily and effectively implemented in the design of a new subdivision or development. These include chicanes, lateral shifts, intersection alignment, road narrowing, and intersection bulb-outs or neckdowns. Each of these is described briefly.

Chicanes involve the construction of a series of reverse curves, as shown in Figure 20.36. While these can be effective in restricting driver speed, care must be taken during the design to prevent drivers from being able to take a straight line through the curves. The offset between the curves should be at least one full lane, and preferably the entire roadway width. In addition, the deflection angles should be at least 45° in order to be sufficient to induce lower speeds. Properly designed, chicanes can be one of the most effective

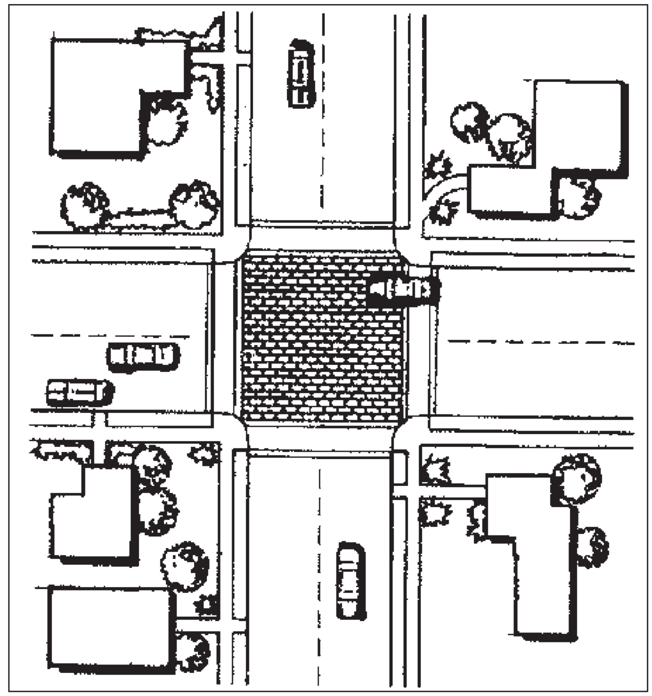


FIGURE 20.35 Raised intersection. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

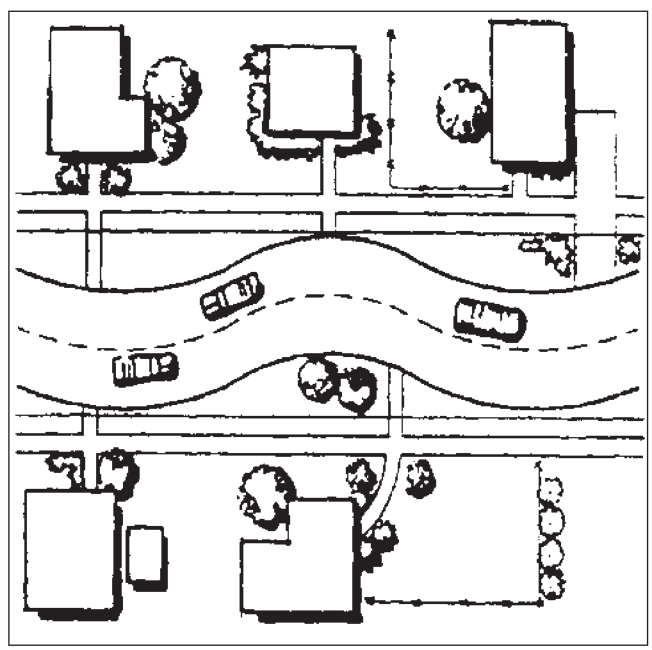


FIGURE 20.36 Chicanes. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

methods of speed control, as they can be a continuous feature of the roadway, eliminating the driver tendency to speed from one traffic-calming measure to the next.

Lateral shifts involve introducing a horizontal offset into a straight alignment. Properly designed, lateral shifts can be used not only on local roads, but on collectors and arterials as well. Both the degree of the lateral shift and the angle of the deflection are factors that determine the degree of speed reduction obtained. As with chicanes, a lateral shift of at least one lane and a deflection of 45° are required. In addition, the issue of drivers cutting across opposing traffic lanes to circumvent the lateral shift can be a concern. However, there are design measures to discourage such behavior (see Figure 20.37).

Realigned or modified intersections are an effective measure for controlling speeds along the through street of a "T" intersection. In the realigned intersection, the intersection is designed as more of a "Y" than a "T," by introducing curved sections that effectively eliminate the straight through movement (see Figure 20.38).

Both road narrowing and intersection bulb-outs or neckdowns are speed control measures that operate on the principal of reducing the width of pavement available to motorists. A bulb-out involves extending the curb lines at the intersection into the parking lanes. (See Figure 20.39.) As a speed control measure, bulb-outs are effective primarily on local streets where there is only one travel lane in each direction. However, bulb-outs are also effective at enhancing pedestrian safety, particularly on wider, multilane streets, as they reduce the distance that must be traversed to cross the intersection. The addition of a median island can provide additional pedestrian safety at wider intersections by providing a refuge, particularly at signalized intersections where the cycle length might make it difficult to complete the crossing before the signal changes.

Other road-narrowing measures include the construction of median islands or curb extensions in the middle of the block to pinch the roadway width and induce mo-

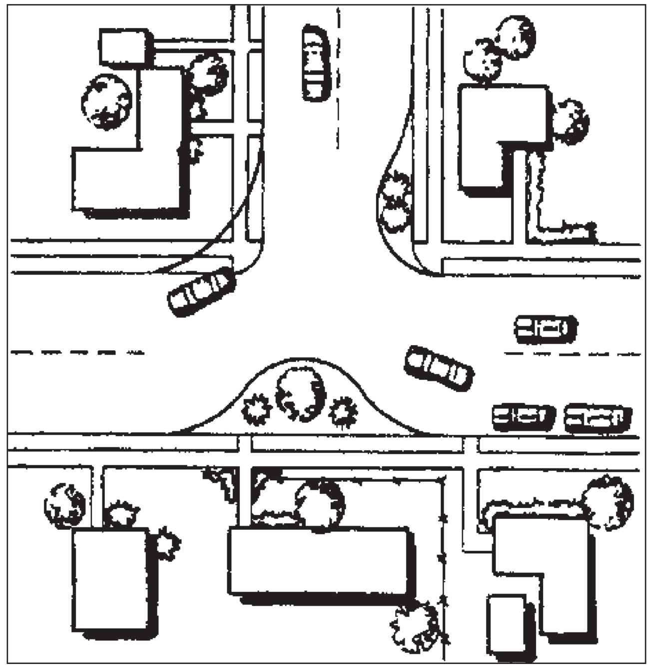


FIGURE 20.38 Realigned intersection. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

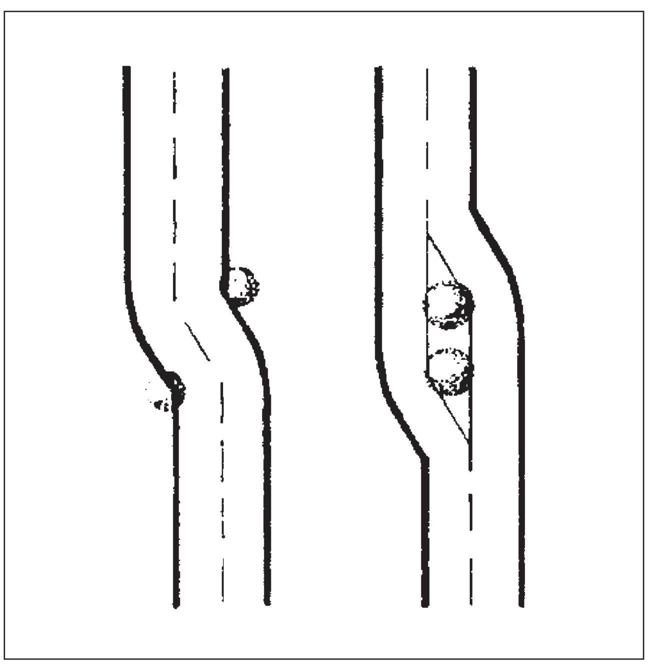


FIGURE 20.37 Lateral shifts. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

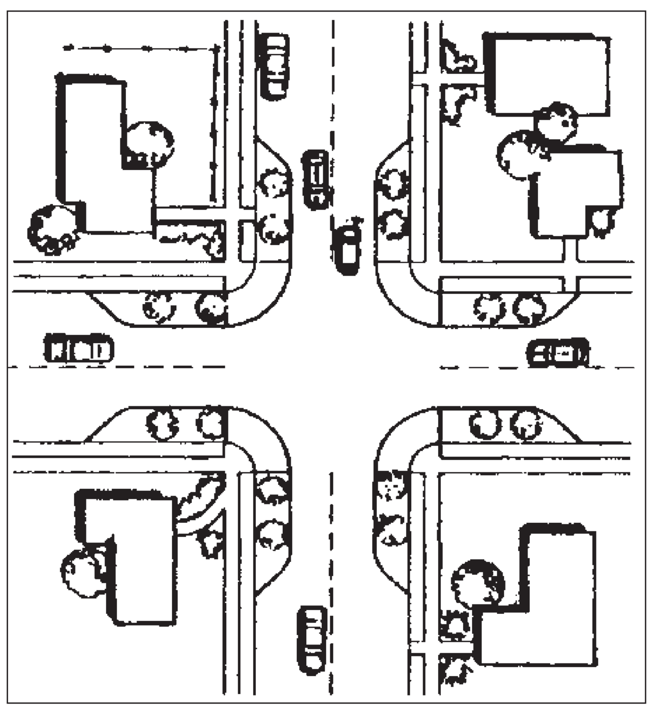


FIGURE 20.39 Bulb-outs. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

torists to reduce their speed. (See Figure 20.40.) Median islands are particularly effective near intersections and along curved roadway segments. At an intersection the median island serves to slow turning movements by forcing vehicles to stay within their own lane and not swing into opposing traffic, while along curved roadway segments the island prevents drivers from attempting to "flatten the curve" by crossing the roadway centerline. Curb extensions, meanwhile, are utilized primarily on tangent roadway sections. Curb extensions typically restrict the width of the travel lanes in each direction (sometimes in conjunction with a median island). While in some areas curb extensions are designed to reduce a roadway to single-lane operation, this implementation is generally discouraged in the United States due to the perceived increased risk of head-on collisions.

Roundabouts and Traffic Circles

The last traffic-calming measures applicable to new developments are the modern roundabout and neighborhood traffic circle. The primary difference between the modern roundabout and the neighborhood traffic circle is scale: roundabouts are designed for somewhat higher traffic volumes and speeds than traffic circles and, consequently, require additional land to construct. (See Figure 20.41.) However, both operate on the same principles: traffic within the roundabout or circle has the right of way, with entering traffic controlled

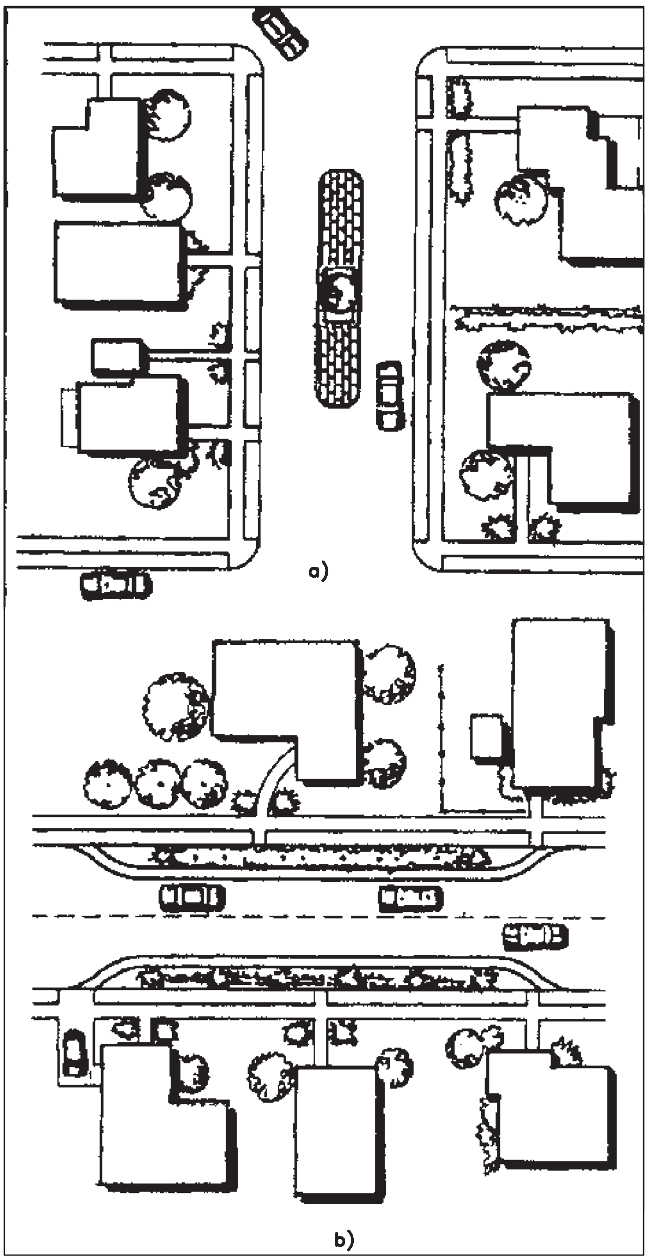


FIGURE 20.40 (*a*) Median island and (*b*) narrowings. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

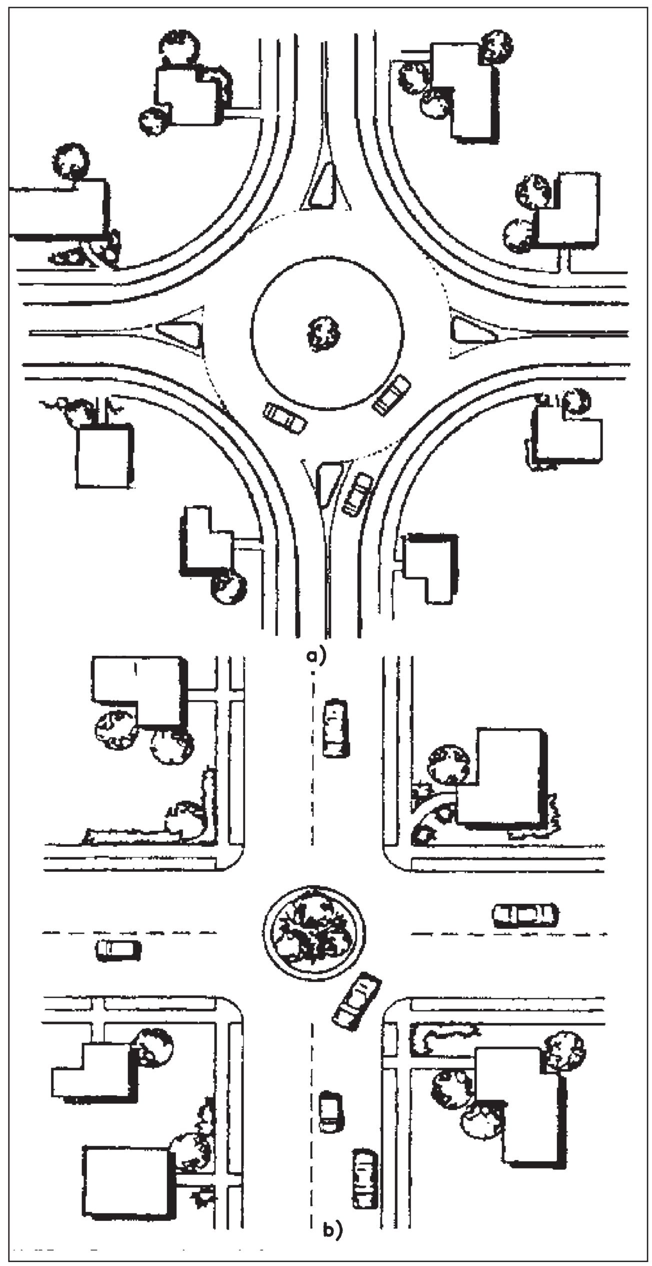


FIGURE 20.41 (*a*) Roundabout and (*b*) neighborhood traffic circle. (© 1999 Institute of Transportation Engineers, 1099 14th Street, NW)

by yield signs. By forcing all vehicles to travel counterclockwise around the central circle, these measures force vehicles to reduce speed through the intersection. Roundabouts and traffic circles have been found to be highly effective at reducing the number of intersection accidents. In addition, accidents that do occur tend to be less severe than those for signalized or stop-controlled intersections. This is due primarily to the fact that the design of roundabouts and traffic circles greatly reduces the possibility of head-on and right-angle collisions. The circulating nature of these designs limits most accidents that do occur to sideswipe accidents.

One major concern regarding traffic circles is their accessibility to larger vehicles. As the neighborhood traffic circle is generally implemented within approximately the same right-of-way as a standard intersection, the construction of the central circle can greatly inhibit the maneuverability of trucks or buses, which might not be able to negotiate the tight radius around the circle. One solution is to include a *truck apron* around the inner circle. This is a paved outer ring with a mountable curb that allows the larger vehicles to more easily negotiate the tight radius. The mountable curb, which can easily be negotiated by larger vehicles, helps to prevent smaller vehicles from taking advantage of the apron to travel through the intersection at a higher speed.

There are a number of resources available to assist in the design of roundabouts. In the absence of local or state guidelines, readers are directed to FHWA Publication No. FHWA-RD-00-067, *Roundabouts: An Informational Guide*. In addition, several software packages are available to assist in the design of roundabouts, including RODEL, aaSIDRA, VISSIM, and Paramics.

TYPICAL STREET PLAN AND PROFILE

Engineering drawings serve three main purposes: to assure the design review agencies that the design conforms to all codes, standards, and ordinances; to provide the contractor a clear, unambiguous detail of how and where to construct the road; and to serve as a record of what was constructed.

The plan and profile of the road drawings (see Figure 20.42) should be at an appropriate scale. The PGL reference line (usually the centerline of the street) shows the stationing at 100-foot increments. This same stationing is used both in the plan and in profile views. Station equalities at intersections are delineated in both views along with the stations where the proposed roads meet the existing roads or end at boundary limits. Many times this same reference line and stationing are used to locate proposed utilities, storm sewers, and other construction-related features.

In the plan view, basic horizontal curve information includes stationing of the PC and PT points, radius, arc length, and delta angle. Tangent length, chord length, and chord bearing are helpful but not necessary. The vertical curve information in the profile views shows the tangent grades and the stationing of the PVC, PVT, and PVI, with elevations with respect to the PGL. If the road is superelevated, the profile should show where normal crown ends, where the transition to superelevation begins and ends, and the limits and rate of full superelevation.

Elevations along the PGL are shown on the profile view every 50 feet along longitudinal tangents. Through vertical curves the elevations are shown in shorter increments—every 25 feet in normal circumstances and less for short vertical curves. In addition, elevations are frequently shown for the left and right edge of pavement (EP) or for top of curb (TC). In complex situations elevations might be shown every 10 feet and at locations in addition to the PGL—for example, left and right EP or TC.

Many contractors construct the curb and gutter section before placing the pavement. It is helpful to provide the top of curb elevations, especially at all curb return points. The curb return points are often referenced to the centerline stationing.

Indicating Sight Distance on Plans and Profiles

Sight distance depends on the height of the driver's eye and the height of a visible object or obstruction in the driver's line of sight. The height of the eye is assumed to be 3.5 feet for passenger-type vehicles (7.6 feet for large trucks) and the height of the object is 2 feet for determining adequate stopping sight distance on vertical curves. In land developments the sight line is often restricted to the right-of-way line because landowners later may plant shrubbery to the limits of their property. Situations where sight lines cross limits outside the right-of-way can be resolved by including provisions restricting obstructions within the sight line area.

To assure reviewing agencies that adequate sight distance has been provided, the engineer might consider showing the lines of sight on horizontal curves, vertical curves, and at intersections. Local criteria may even require this detail on the plan and profile sheets. In most cases the stopping sight distance on a vertical curve has been accounted for if the ratio of the length of the curve to the algebraic difference of tangent gradients is greater than the K value. Likewise, criteria dictating an absolute minimum radius for horizontal curves put the line of sight within the pavement area and away from obstructions that would encroach upon the line of sight near the right-of-way. Nonetheless, a reasonable comfort level for the design can be attained with periodic spot checks for horizontal and vertical stopping sight distances.

Intersection sight distances should be checked always, both in plan view and in profile view. In plan view the location of the vehicle is a nominal distance back from the face of curb (or the edge of pavement) of the through street. The required distance is measured along the centerline of the oncoming travel lane. The line of sight is the connection of the two points. If the line of sight extends into private property, a sight easement may be required before the plans are approved.

To show adequate intersection sight distance in the profile view, the station of the intersection is plotted an elevation of 3.5 feet above the pavement elevation to represent the height of the eye. On either side of this station another point is plotted a distance equal to the required sight distance for inter-

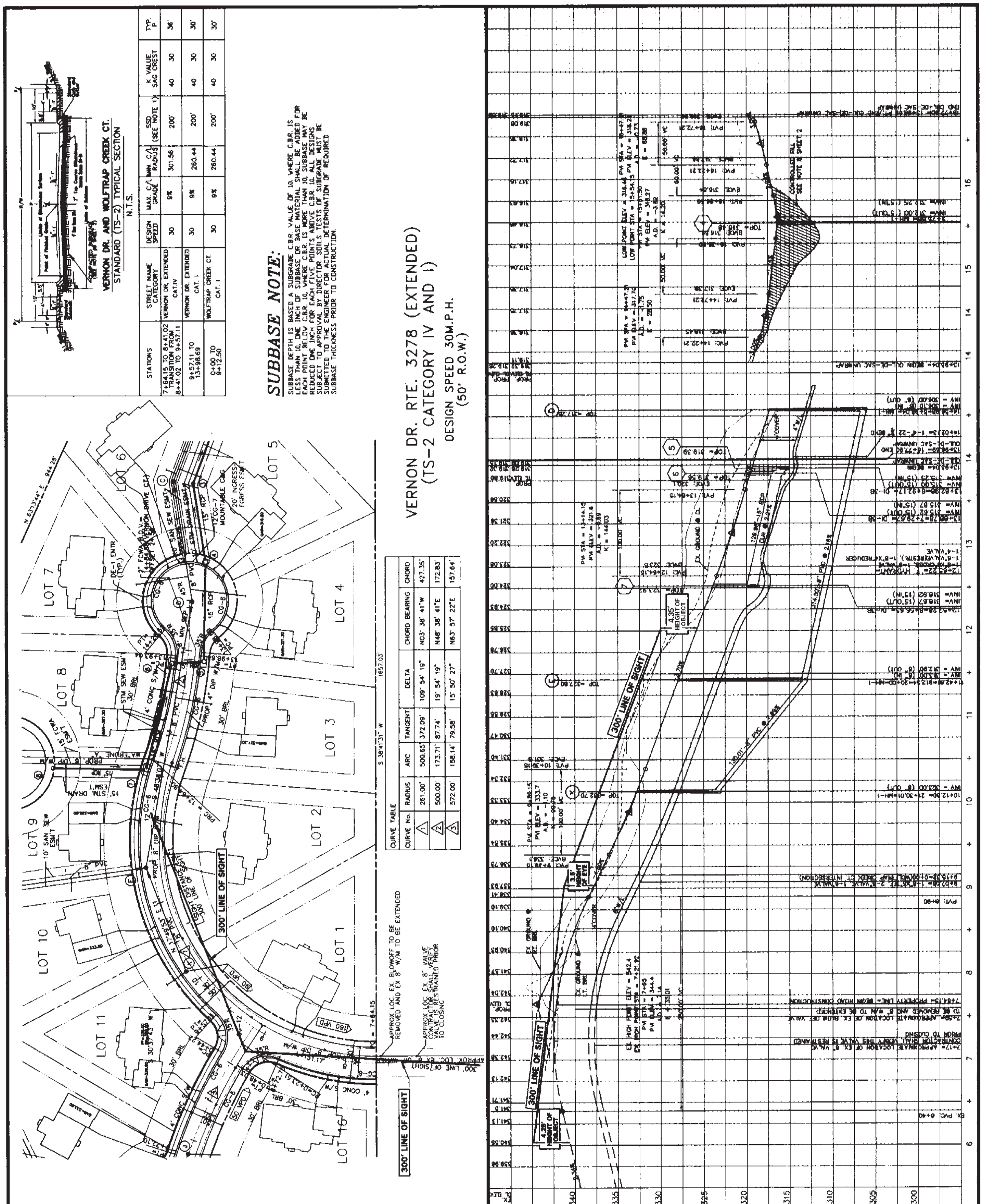


FIGURE 20.42 Typical street plan and profile.

TABLE 20.4 Geometric Design Standards for Residential Subdivision Streets

		Horizontal and Vertical Controls Maximum 2:1 cut or fill slope					Roadway Section Criteria					
		Curve Data			Minimum Sight Distance				Shoulder and Ditch Roadways Minimum ditch width (front slope) should be 4 ft or greater, based on slopes of 3:1 (Gentler slopes promote homeowner maintenance of ditches) *Width includes 3:1 for G.R. installation			
Projected Traffic Volume (ADT)	Minimum Design Speed (MPH) (Not Posted Speed)	Minimum Centerline Radius	Super Elevation	Suggested Maximum % Grade	Stopping	Intersections	Minimum Width (Curb to Curb)[6] (Parking Assumed)	Clear Zone without Parking (Measured from Face of Curb)[9]	Minimum Pavement Width	Fill w/ G.R.*	Cut or Fill w/o G.R.	Clear Zone
Up to 400	20	110′[10]	None	10%[2]	125′[7]	200′	28′[4]	1.5′	18′	7′	4′[1]	6′[3]
401–2000	25	200′	None	10%[2]	155′	280′	36′	1.5′	22′[7]	9′	6′[8]	7′
2001–4000	30	335′	None	10%[2]	200′	335′	40′[5]	6	24′	11′	8′	12′

For streets with volumes over 4000 or serving heavy commercial or industrial traffic; use the appropriate geometric design standard. (see VDOT's Road Design Manual)
The roadway with the highest volume will govern the sight distance.
Right-of-way requirements can be found in Section B-4.1 Right of Way.
[1]When pedestrian facilities are provided behind ditches, the shoulder width may be reduced to a minimum of 2 ft.
[2]For mountainous terrain, maximum percent of grade may be 16% for ADT up to 400 and 14% for 401–4000 ADT.
[3]Clear zone widths may be reduced with the concurrence of the resident engineer where terrain or social/environmental impact considerations are appropriate.
[4]26 ft allowed for streets <400 vpd with concurrence of local officials.
[5]36 ft allowed for streets that are internal to the subdivision, with concurrence of local officials.
[6]Pavement widths may be reduced if parking is not allowed.
[7]18 ft minimum with < 600 ADT in mountainous terrain. For normal conditions 20 ft minimum with < 1500 ADT.
[8]2 ft minimum in mountainous terrain with < 600 ADT. For normal conditions 5 ft minimum with 401–1500 ADT.
[9]For curb and gutter streets with parking lanes, the clear zone is accommodated within the parking lane. However, VDOT has established a 3-ft minimum setback requirement behind the curb.
[10]100-ft minimum radius allowed in mountainous terrain.

sections a height of 4.35 feet above the pavement. If these two points are unobstructed, then adequate sight distance for the intersection has been provided (see Figure 20.42).

SAMPLE DESIGN CRITERIA FOR LOCAL STREETS

It has been emphasized throughout this chapter that standards and criteria dictating local street design are controlled mainly through local and state public agencies. An example for the design criteria for local streets as given in the *Highway Design Manual—Subdivision Street Requirements* by the Virginia Department of Transportation (2005) is presented in Table 20.4.

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ADDITIONAL READINGS

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NCHRP Report 500, vol. 10. A Guide for Reducing Collisions Involving Pedestrians.

NCHRP Report 500, Vol. 12. A Guide for Reducing Collisions at Signalized Intersections.

CHAPTER 21

STORM DRAINAGE DESIGN

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INTRODUCTION

Drainage systems are divided into two categories: minor and major. The minor system, which consists of swales, small ditches, gutters, small pipes, and the other various types of inlets and catch basins, collects and conveys runoff to a discharge area or impoundment. Components in the minor system are sized to carry runoff generated by the more frequent, short-duration storm events. The major drainage system includes natural streams, channels, ponds, lakes, retention and detention facilities, large pipes, and culverts. Design criteria for the major system are based on significant amounts of rainfall produced by the less frequent, long-duration storms and are further governed by the hydraulic concepts related to bridges and large conveyance structures.

Storm drain design requires two basic types of analyses: the hydrologic aspect of estimating runoff and the hydraulic aspect of sizing the components. Although there are numerous techniques to estimate runoff, the one selected for design of a particular component depends on the following factors:

- What is being designed
- Type of input data available
- Type of output data required
- Cost effectiveness of the technique
- Required accuracy
- Size of watershed
- Accepted design standards of the approving agency(ies)

Generally, the design of minor-system components requires only the determination of peak runoff discharges, whereas major-system components require not only the peak discharges but the time variation of runoff for an effective design. Analysis of major systems may include detailed hydrology and hydraulic modeling using one- and two-dimensional modeling software. This chapter includes a brief discussion of the available programs and methodology used in analyzing major systems; however, the primary focus is on computing runoff for small drainage areas for the purpose of sizing minor-system components, such as culvert design and analysis and surface inlets and pipe systems. Analysis of minor systems includes hydraulic head loss through the system and hydraulic grade line (HGL) computations. (See Figure 21.1.)

PAVEMENT DRAINAGE

Stormwater runoff on roads is a safety hazard in numerous ways. Hydroplaning, reduced visibility, and icy conditions are dangerous to vehicle occupants and pedestrians. In an urban setting, these hazardous conditions are substantially magnified due to the increased traffic and pedestrian density. It is imperative to effectively remove the stormwater runoff from roads quickly and efficiently to mitigate the safety risks. Effective removal of runoff is affected by the geometric characteristics of the roadway, such as longitudinal slope, cross slope, type of curb and gutter section, and ditch section. These geometric characteristics dictate the location and spacing of inlets and catch basins.

Flow in Curb and Gutter

Most urban and suburban land development projects of moderate to high density use curb or curb and gutter. For drainage purposes, the gutter is considered as part of the pavement width. In many cases, streets are constructed with composite gutter and pavement sections, where the gutter

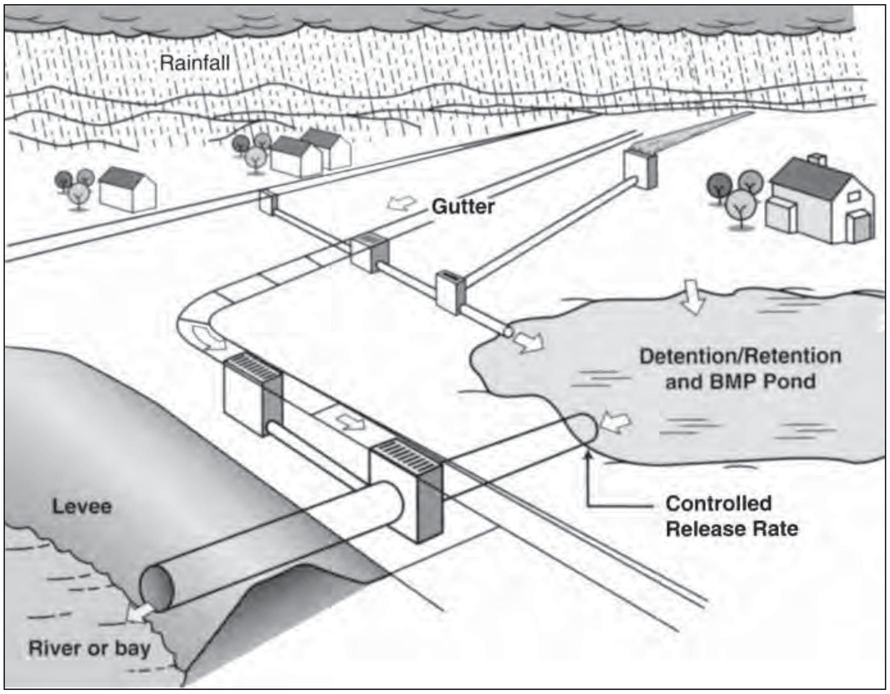

FIGURE 21.1 Typical urban drainage system.

portion has a greater cross slope than the pavement. A composite gutter section results in a decrease in elevation of the flow line at the face of the curb relative to where the flow line would be if the pavement were extended to the face of the curb at the designed cross slope. In these instances, the gutters typically vary between 1 foot and 3 feet wide, depending on local standards. The steeper cross slope of the gutter concentrates the flow toward the gutter to improve inlet efficiency and minimize the width of the runoff as it encroaches onto the travel lanes (spread).

There are some examples, such as on the inside (left) lane adjacent to a raised median, where composite gutters are not provided and the roadway surface and slope tie directly into the face of the curb. These are sometimes referred to as *header curbs,* and the engineer should consider the lack of the gutter section when calculating flow along curb and gutter sections. The Federal Highway Administration's HEC-12, *Drainage of Highway Pavements,* is the basis for many local guidance design standards and criteria.

Flow conveyed in gutter sections with uniform cross slope is:

$$Q = \frac{0.56}{n} S_x^{5/3} S^{1/2} T^{8/3} \tag{21.1}$$

which is a modification of the Manning equation and accounts for the disproportionate ratio of depth to top width of water surface. In the equation, Q = discharge (cfs), n = Manning's n coefficient, S_x = pavement cross slope (ft/ft), S = longitudinal slope of the gutter (ft/ft), T = width of flow or spread (ft), which is the distance from the face of the curb to the water line limits in the pavement. Values for Manning's n coefficient for various pavement types are given in Table 21.1. The nomograph in Figure 21.2 is the solution to this equation for either V-shaped or triangular gutter configurations.

TABLE 21.1 Manning's *n* Values for Street and Pavement Gutters

Type of Gutter or Pavement	Range of Manning's *n*
Concrete gutter, troweled finish	0.012
Asphalt pavement:	
Smooth texture	0.013
Rough texture	0.016
Concrete gutter with asphalt pavement:	
Smooth	0.013
Rough	0.015
Concrete pavement:	
Float finish	0.014
Broom finish	0.016
For gutters with small slope, where sediment may accumulate, *increase* above values by n of	0.002

Note: Estimates are by the Federal Highway Administration.
Reference: USDOT, FHWA, HDS-3 (1961).

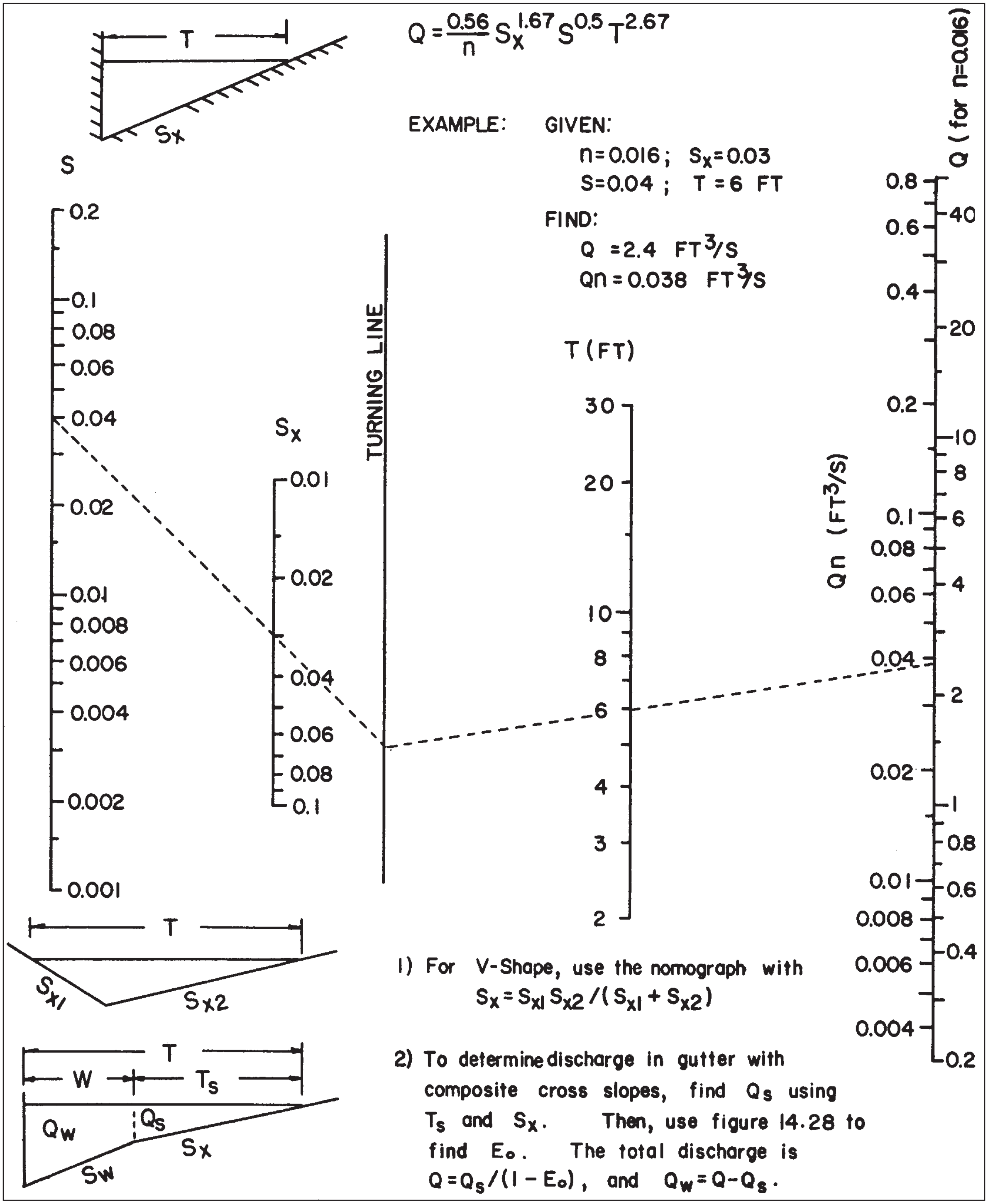

FIGURE 21.2 Nomograph for flow in triangular gutter sections.

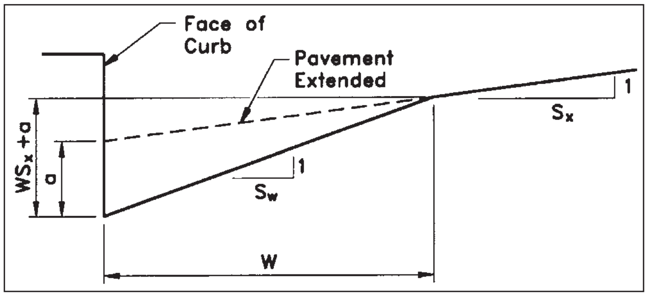

FIGURE 21.3 Composite gutter section nomenclature.

The cross slope of the depressed gutter section measured relative to the pavement cross slope is designated as S'_w and is equal to the depression divided by the width of the gutter:

$$S'_w = \frac{a}{W} \tag{21.2}$$

Hence, the actual cross slope S_w is:

$$S_w = S'_w + S_x \tag{21.3}$$

The relationship between these terms is illustrated in Figure 21.3.

Flow in composite gutter sections is computed by separating the flow into two prisms: (1) the flow in the pavement section and (2) the flow in the depressed gutter area. The flow in the pavement section is:

$$Q_s = \frac{0.56\, d_2^{8/3} S^{1/2}}{n S_x} \tag{21.4}$$

where $d_2 = (T - W)\, S_x$, as shown in Figure 21.4; d_2 is the depth of flow at the break point of the gutter-pavement interface; and W is the width of the gutter.

The flow in the gutter section is given as:

$$Q_w = \frac{0.56\, (d_1^{8/3} - d_2^{8/3}) S^{1/2}}{n S_w} \tag{21.5}$$

where d_1 is the depth of flow at the curb and S_w is the cross slope of the gutter. Note that Equation 21.5 computes the flow in prism ABCD′ by subtracting the flow in triangle CDD′ from the flow in triangle ABCD of Figure 21.5.

Because of the numerous variables involved in the computations of flow in composite gutters, a relationship between the gutter flow ratio $Q_w/Q(= E_o)$, W/T, and S_w/S_x has been developed. Figure 21.6 is a nomograph depicting this relationship and assumes that the Manning's roughness coefficient for the gutter and pavement are the same.

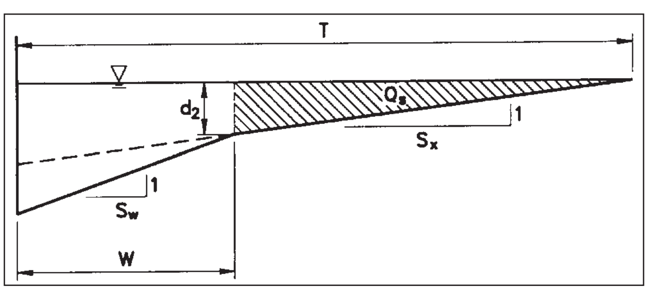

FIGURE 21.4 Flow in pavement section.

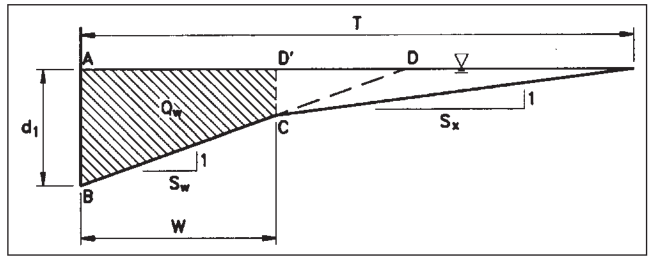

FIGURE 21.5 Flow in gutter section.

In most urban areas, the allowable spread of the flow into the street is given in local design manuals. The general rule of thumb for urban-type secondary streets is to limit the spread to one-half the lane width as measured from the curb. Some primary road designs, such as interstates, require that the spread not encroach at all on the travel lane. The spread is a function of the longitudinal and transverse slope of the pavement. Typically, drainage design of streets involves the sizing and spacing of the inlets based on limitations of the spread, with a given geometry of the street. However, to determine the spread T, given other parameters, involves a trial-and-error procedure, since no direct solution for T is available from Equations 21.4 and 21.5.

EXAMPLE 1

Find the spread of flow for a street section with a gutter width W of 2 feet, curb height = 6 inches, S_w = 1 inch per foot, pavement cross slope of ¼ inch per foot

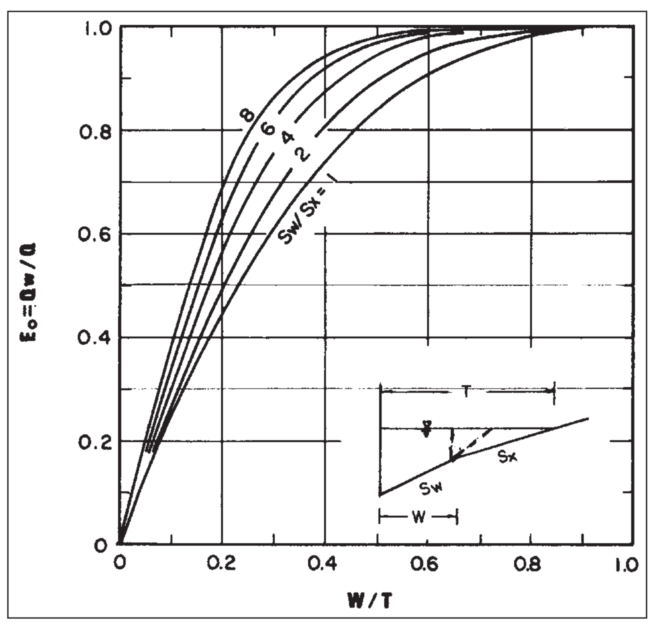

FIGURE 21.6 Ratio of frontal flow to total gutter flow.

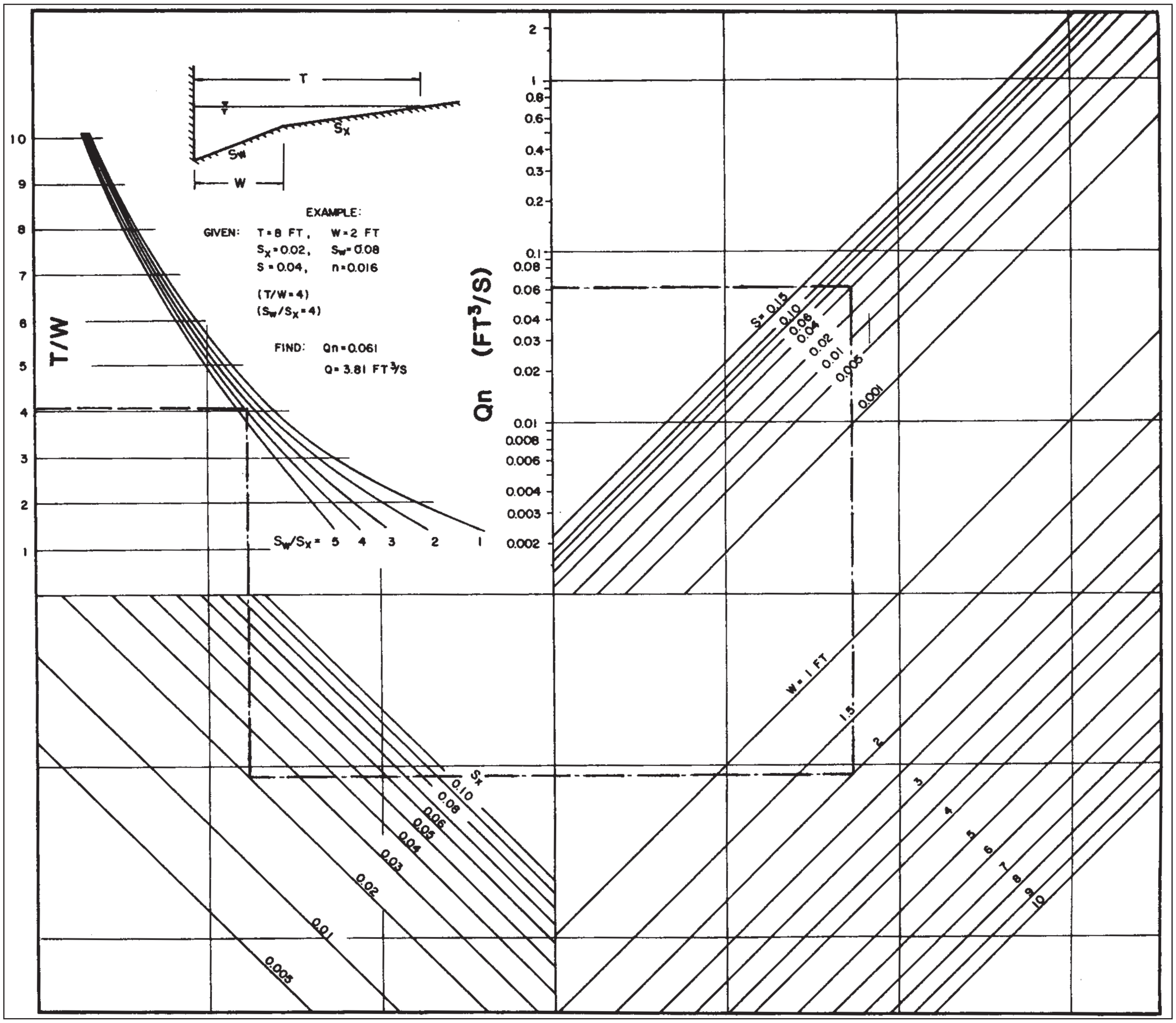

Figure 21.7 Flow in composite gutter sections.

(S_x = 0.0208), longitudinal slope of 3 percent, and a design discharge of 3.5 cfs (assume n = .015 for both pavement and gutter).

Equations 21.4 and 21.5 can be used simultaneously to solve for the two unknowns T and Q_w (recall that $Q = Q_w + Q_s$). Because a direct solution is difficult due to the exponential form of the equations, the nomograph of Figure 21.7 can aid the computations.

Extend a horizontal line from 0.053 [(= 3.5)(0.015)] on the Q_n to intersect the S = 0.03 line. From this point, draw a vertical line to intersect the W = 2 feet line. Continue horizontally and intersect the S_x = 0.02 at the bottom left quadrant of the nomograph. Extend a vertical line to S_w/S_x = 0.083/0.020 = 4.1. A horizontal line drawn from this point to the T/W scale gives a value of 4.0. This translates to a spread of T = (2)(4.0) = 8.0 feet.

Check the depth at the curb:

$$d_1 = TS_x + W(S_w - S_x) \tag{21.6}$$

$$= (8.0)(0.02) + 2(0.083 - 0.02)$$

$$= 0.29 \text{ feet}$$

Since 0.29 feet < 0.5 feet, the design flow will not overtop the curb.

Often the values for S_x, S_w, and S must be interpolated on the nomograph, which may contribute to some error in reading the T/W scale. In these situations the estimated value for T can be used as a beginning trial value to substitute into Equations 21.4 and 21.5. The value for T is adjusted to get $Q_s + Q_w = Q$.

Inlets

Inlets intercept surface runoff and transfer it to the pipe network. The three basic types of inlets used with pavement drainage are the curb opening inlet, the gutter (or grate) inlet, and the combination of the curb and grate inlet. The curb opening inlet collects runoff through a vertical opening, along the face of curb. These inlets consist of a manhole structure with a throat and concrete slab fitting on the top. An opening in the slab allows access to the structure. A gutter (or grate) inlet lies flat in the pavement or gutter and allows runoff to fall directly down and into the system. Figure 21.8 shows these various inlets.

An inlet's flow capacity is the maximum amount of runoff that it can intercept, as determined by the combined effects of longitudinal and transverse slopes of the road, roughness of the pavement, depth of flow at the inlet, and the configuration of the inlet opening. Flow through an inlet is either orifice flow or weir flow depending on the flow depth at the opening. Under either case, the capacity of the inlet is a function of the depth of flow forcing the water through the opening. For a given street geometry and flow conditions (i.e., flow depth), a given inlet has a specific interception capacity. When the flow exceeds the capacity of the inlet, a portion of the flow is not intercepted. The ratio of the intercepted flow to the total gutter flow Q_i/Q_T is the efficiency of the inlet. Any flow not intercepted by the inlet is termed *carryover* or *bypass* flow. This bypass flow must be added to the runoff computed for the next downstream inlet in the analysis. Obviously there can be no carryover from inlets located in sump (low point) areas. Additionally, the designer should limit the carryover flows in pavement areas where the cross slope of the road changes directions; this is to avoid creating an unsafe situation due to flow crossing or icing of the travel lanes.

The physical characteristics of the street and inlet affect the flow velocity at the inlet. As gutter flow velocities increase, the depth at the curb decreases and the amount of bypass flow increases. This is equivalent to a decrease in both interception capacity and efficiency for curb opening–type inlets. The effective flow depth at a curb opening inlet is increased by depressing the gutter along the throat length. Most inlets have a 2- to 3-inch depression to improve interception capacity. Everything else being equal, increasing depth at the curb (by increasing pavement cross slope) increases both the interception capacity and the efficiency. Although grate inlets may be more effective on higher longitudinal slopes, they present more of an obstruction to pedestrians and bicycle traffic and are susceptible to clogging.

The type of inlet used is governed by the standards of the local jurisdiction. The department of transportation and the local department of public works can be very particular about the types of inlets allowed in rights-of-way.

Inlet Capacity

Typically, the design standards for a locality include capacity charts, nomographs, or equations for the inlets accepted by the review agencies. Manufacturers of inlets often perform their own tests on grate inlets and provide the capacity information upon request.

Curb-Opening Inlets on Grade. For curb opening–type inlets, the length of curb opening necessary for 100 percent efficiency in a street section with undepressed gutter and constant cross slope is:

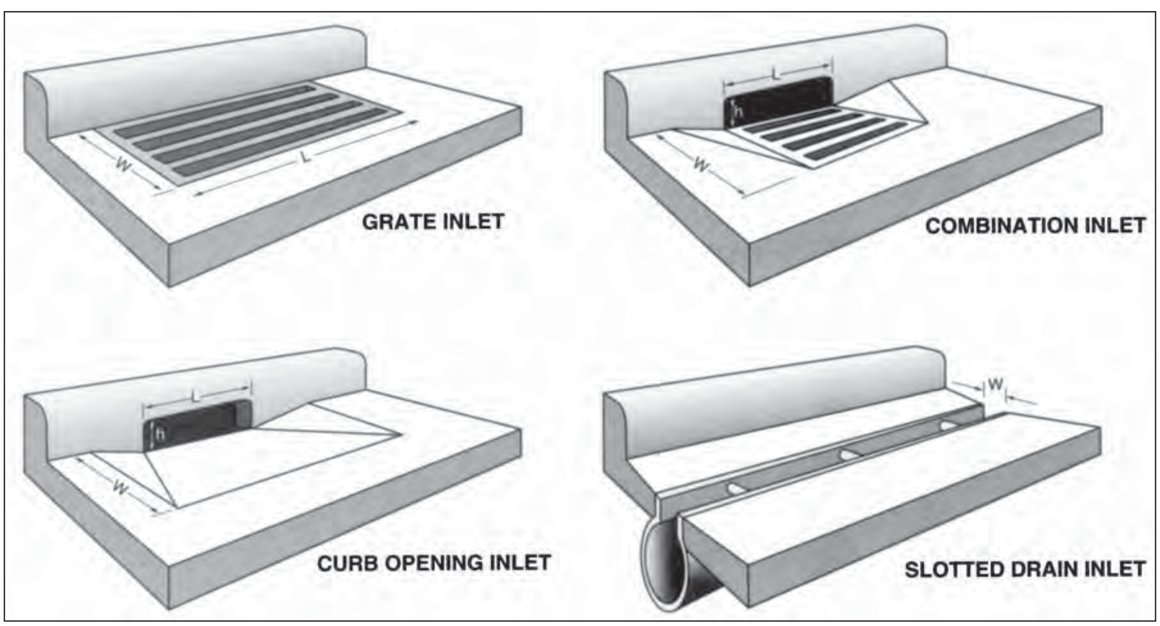

FIGURE 21.8 Various types of curb inlets and gutter inlets.

$$L_T = 0.6\, Q^{0.42} S^{0.3} \left(\frac{1}{nS_x}\right)^{0.6} \qquad (21.7)$$

where L_T = curb opening length required for 100 percent interception (ft), Q = gutter flow (cfs), S = longitudinal street slope (ft/ft), S_x = cross slope (ft/ft), and n = Manning's n coefficient for the pavement. The nomograph of Figure 21.9 can be used in lieu of the equation.

For a depressed curb opening inlet, the length of opening is the same as Equation 21.7, with the S_x term replaced by the equivalent cross-slope term S_e. This term is used to account for the gutter depression. The equivalent cross slope is given as:

$$S_e = S_x + S'_w E_o \qquad (21.8)$$

The efficiency E of a curb opening inlet is given as:

$$E = \frac{Q_i}{Q} = 1 - \left(1 - \frac{L}{L_T}\right)^{1.8} \qquad (21.9)$$

where L is the actual length of the curb opening. This is shown graphically in Figure 21.10.

Example 2

Determine the throat length required for 100 percent interception for the values of the preceding example.

1. Since this is a composite gutter section, the equivalent cross slope is used as calculated in Equa-

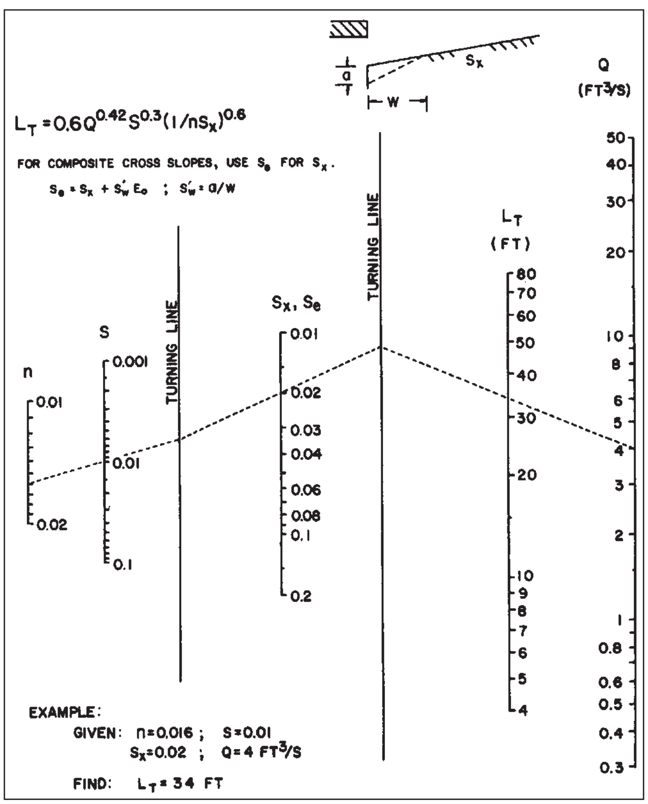

Figure 21.9 Curb opening and slotted-drain inlet length for total interception.

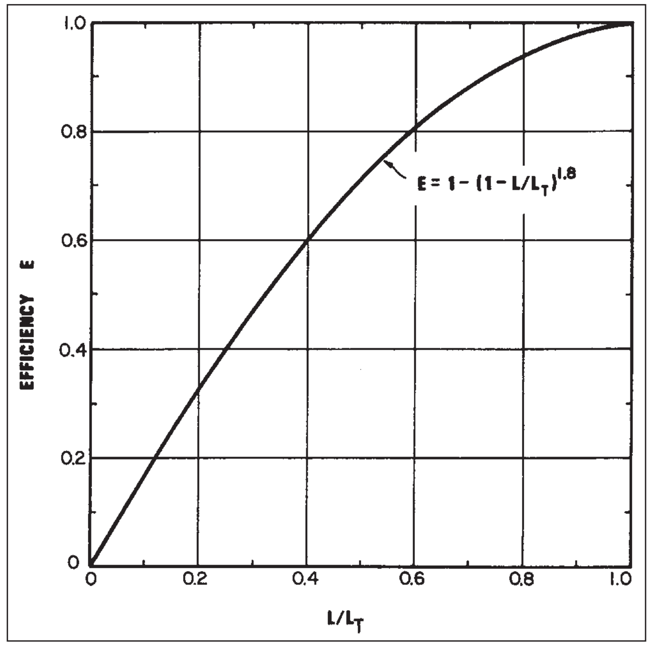

Figure 21.10 Curb opening and slotted-drain inlet interception efficiency.

tion 21.8. Given $S_w/S_x = 4.1$ and $W/T = 0.25$, Figure 21.6 reads a value of $E_0 = 0.70$; S'_w is still required to solve Equation 21.8.

$$S'_w = \frac{a}{W} = \frac{0.125}{2} = 0.063 \qquad (21.10)$$

where $a = w(S_w - S_x)$

$$= 2(0.0833 - 0.0208) \qquad (21.11)$$

$$= 0.125$$

2. The equivalent cross slope is:

$$S_e = 0.0208 + 0.063(0.70) \qquad (21.12)$$

$$= 0.065$$

3. Substituting the values into Equation 21.7:

$$L_T = 0.6(3.5)^{0.42}(0.03)^{0.3}\left(\frac{1}{(0.015)(0.065)}\right)^{0.6} \qquad (21.13)$$

Since most throat lengths are available in 2-foot increments, a 24-foot throat length would be specified for this situation.

Most manufacturers do not make inlets with throats longer than 20 feet. Therefore, the designer would have to consider the overflow from this location to be included at the next downstream location. Or, if 100 percent interception is required, moving the inlet upstream or adding another inlet upstream to reduce the flow to this structure should be considered. Note that once S_e was determined, the required throat length could have been found using Figure 21.9. Also, the answer does not account for the residual storage effects of an additional inlet or local depression, which is standard in many jurisdictions.

Curb Opening Inlets in Sag Locations. These act as a weir for gutter flow depths less than or equal to the height of the opening. At depths greater than 1.4 times the height of the opening, the inlet operates as an orifice. Between these depths, the flow is in transition. The interception capacity for a depressed inlet as given by the weir equation is:

$$Q_i = C_w(L + 1.8W)\,d^{1.5} \qquad (21.14)$$

where C_w is the weir coefficient (≈ 2.3), L is the length of the opening (e.g., throat length), W is the lateral width of the depression, and d is the depth of flow at the curb as measured from the normal cross-slope gutter flow line. For an undepressed inlet, W is equal to 0.

When flow in the gutter exceeds the height of the curb opening inlet by a factor of 1.4, the opening acts as an orifice with the capacity given as:

$$Q_i = C_o hL\sqrt{2gd_o} = C_o A\sqrt{2g\left(d_i - \frac{h}{2}\right)} \qquad (21.15)$$

where C_o is the orifice coefficient (usually 0.67), h is the height of the opening (feet), L is the length of the opening (feet), d_o is the effective head on the center of the orifice throat, A is the area of the opening (square feet), and d is the depth at the lip of the curb opening (feet). Typical opening configurations for curb inlets are shown in Figure 21.11. The computed capacity for the inlet depends on proper interpretation of the height of the opening, since the height depends on the configuration of the throat opening.

Grate Inlets. The capacity of a grate inlet depends on pavement geometry, amount of flow, and the configuration of the grate. Flow through the grate is affected by the size and spacing of the bars as well as their shape and orientation with respect to flow direction.

Any jurisdiction's design standards identify preferred types of grates. Each type of grate has its own hydraulic capacity chart. The Federal Highway Administration (FHWA) identifies several types of grates and their hydraulic characteristics in HEC-12. For those occasions where a standard grate will not suffice, readers are referred to manufacturers of grates for dimensions and hydraulic characteristics.

Grate Inlets in Sag Locations. Flow through grates located at the lowpoint of a sag vertical curve operates as weir flow for relatively shallow depths. As the depth increases, the flow through the inlet transitions to orifice flow. There is no definitive depth where weir flow stops and orifice flow begins. The range of depth for which the transition between weir and orifice flow occurs depends on geometric and hydraulic characteristics of the grate. The weir equation for grate inlets is:

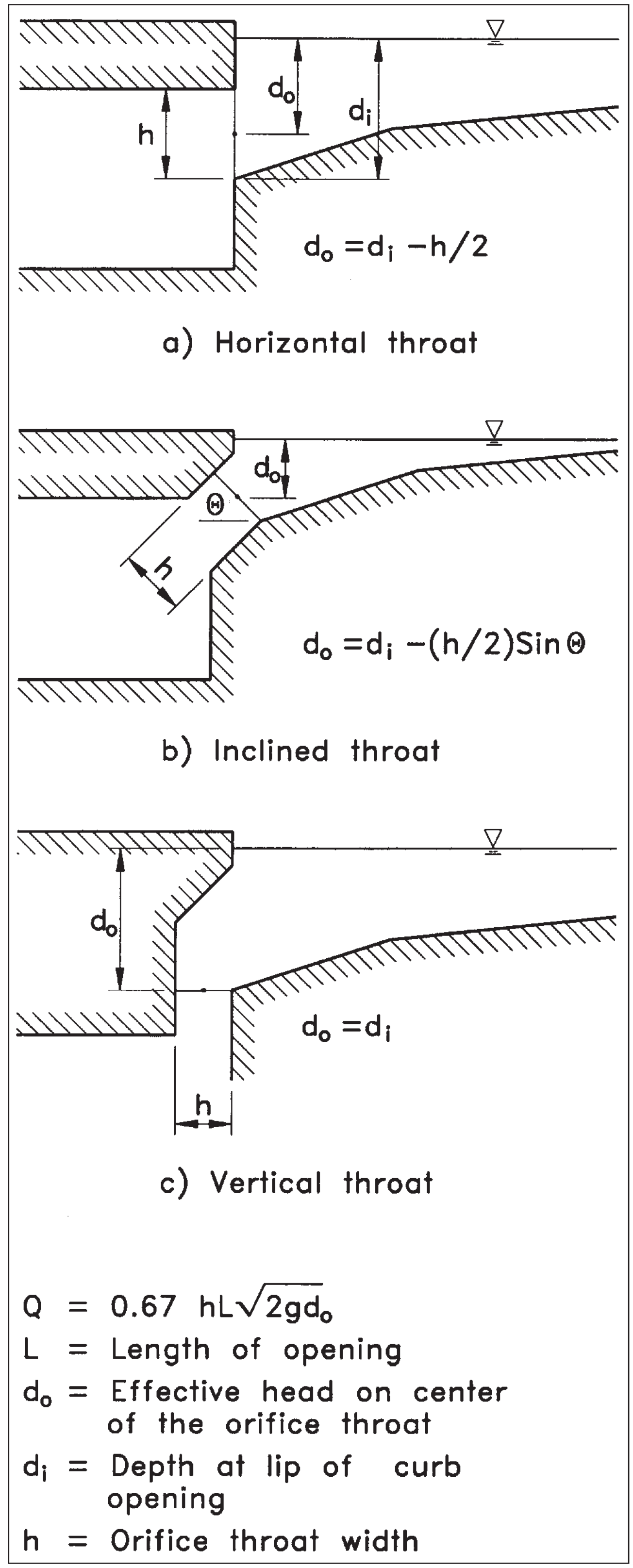

FIGURE 21.11 Throat configuration of curb opening inlets.

$$Q = C_w P d^{3/2} \tag{21.16}$$

where C_w is a weir coefficient dependent on geometry of the opening ($C_w \approx 3.0$), P is the effective length of opening where weir flow occurs (grates located along the face of curb have only three sides where discharge passes through as weir flow), and d is the depth of flow.

The orifice equation for grate inlets is:

$$Q = C_d A \sqrt{2gd} \tag{21.17}$$

where C_d is the coefficient of discharge (≈ 0.67), A is the clear opening area of the grate (ft^2), $g = 32.17$ ft/sec^2, and d is the depth of flow. Orifice discharge through the grate depends on the clear open area, which does not include space occupied by bars, vanes, and other obstructions. Since sag locations are highly susceptible to clogging by debris and trash, many localities require an allowance of 50 percent for clogging.

STORM SEWER AND INLET LAYOUT

The storm sewer design, like most design processes, is an iterative process. The results from one iteration provide the details necessary for further refinement of the design in the next iteration. Each iteration attempts to optimize the design in order to provide adequate drainage control, without an excessive number of inlets or length of pipe. In most cases, design of the storm sewer system requires between two and four iterations. The design of the minor system involves:

- Locating the inlets
- Hydrologic analysis to size the inlets
- Determining the pipe network
- Hydrologic and hydraulic analysis to size the pipes
- Checking to see that all constraints are met, which includes dealing with hydrology and hydraulics, compliance with local criteria and standards, and any impacts to other components of the project

Requisite information to begin design of the storm drain system includes on-site and off-site topographic maps, current and projected land use maps, soil identification maps, floodplain delineation maps, floodplain reports, existing site plans of surrounding property, stream and channel outfall information, and the plans of the proposed conditions of the project. Worksheets of the proposed project in plan view, at a scale of 1 inch = 50 feet or larger are preferable. The worksheets should show proposed and existing topography; layout of the proposed streets, buildings, and parking areas; profiles of the road alignment; horizontal and vertical location of all existing utilities; and any proposed utilities. Much of this existing information should already be in project files, having been accumulated during the course of the project.

Location of Inlets in Streets

Inlets are placed at all low points in sag vertical curves. In sag locations, where there is a higher propensity for clogging of grates, the spread of ponded water presents a traffic hazard. Flanking inlets should be considered, if they are not required by code, in the sump area of a sag vertical curve. The addition of flanking inlets, which limit the spread and ponding at the low point, provides relief when the sump inlet is clogged. Table 21.2 is the Federal Highway Administration's recommendation for spacing of the flanking inlets. This recommendation is based on the desired depth at the curb and the vertical curve length defined by $K = L/A$, where L is the length of the vertical curve and $A = g_2 - g_1$ is the algebraic difference of the tangent slopes of the vertical curve.

TABLE 21.2 Distance to Flanking Inlets in Sag Vertical Curve Locations Using Depth at Curb Criteria

Speed (mph):	20	25	30	35	40	45	50	55	60		65	70
K(= L/A):	20	30	40	50	70	90	110	130	160	167	180	220
Depth @ curb												
0.1	20	24	28	32	37	42	47	51	57	58	60	66
0.2	28	35	40	45	53	60	66	72	80	82	85	94
0.3	35	42	49	55	65	73	81	88	98	100	104	115
0.4	40	49	57	63	75	85	94	102	113	116	120	133
0.5	45	55	63	71	84	95	105	114	126	129	134	148
0.6	49	60	69	77	92	104	115	125	139	142	147	162
0.7	53	65	75	84	99	112	124	135	150	153	159	176
0.8	57	69	80	89	106	120	133	144	160	163	170	188

Reference: USDOT FHWA, *Drainage of Highway Pavements,* HEC-12, 1984.

For an example, what is the recommended distance to the flanking inlets for a 300-foot-long vertical curve with longitudinal slopes of $g_1 = -3\%$ and $g_2 = +3\%$, and the depth of flow at the curb is 0.4 feet?

Solving for K:

$$K = \frac{L}{g_2 - g_1} = \frac{300}{(+3) - (-3)} = 50 \tag{21.18}$$

Entering in Table 21.2 for depth at curb value = 0.4 feet and $K = 50$ gives a distance of 63 feet.

On normal crown street sections two inlets are needed, one on each side of the street at the sump location. Two inlets are also needed if the low point (sump) of a sag vertical curve occurs on a section of road that is superelevated, since the standard gutter on the superelevated side forces the water against the face of curb. Although some localities have a "spill," or reverse gutter, that dispenses the water away from the curb, this is not common in public rights-of-way. In cases where a reverse gutter is an option, only one inlet is needed at the low point of the vertical curve on the low side of the superelevation.

Be aware, however, that in certain situations the location of a low point on the outer edge of the pavement is not always the same as that of the lowpoint on the PGL (profile grade line). For example, the low-point locations may not coincide when a superelevation transition[1] occurs at or near the low point of the PGL. Other potential situations in which this might occur typically involve a superelevation transition and/or pavement widening, as when adding a right-turn lane. To properly locate the drainage inlet, the design engineer should check the elevations of the outer edge of pavement along the superelevation transition segment to determine the location of any false low points.[2] Most urban streets have curbed or curb and gutter sections. In those situations, where the urban street is required to have superelevation through horizontal curves, certain conditions create the situation where a low point occurs and is not in an obvious sump. To attain full superelevation or to go from full superelevation to normal crown (or reverse superelevation in the case of compound curves) requires a length of transition. If the rate of superelevation is greater than the longitudinal rate of grade change, a low point in the gutter area results. Although superelevation transitions through horizontal curves are not considered good practice, this situation, in some instances, cannot be avoided due to other constraints. The engineer should be aware of the conditions that present this predicament and locate the not-so-obvious low point.

Inlet placement in an intersection requires detailed analysis of the intersection street's profiles and cross sections. Intersections have the potential for creating unusual drainage patterns and collection networks. The design of an intersection involves matching the cross slope of the intersecting street with the longitudinal profile of the through street. Curb returns (the horizontal curve portion of the curb used to join the curb of the two intersecting streets) and the cross sections of the intersecting streets, coupled with any horizontal and vertical curves, can create sump areas in the most inconspicuous and least favorable locations.

Drainage patterns can be further complicated by deviations from the cross slopes shown on the typical section, which may be relaxed through the intersection to fit the pavement from the intersecting street to the pavement of the through street. Additionally, the profile of the curb return itself may not follow a known mathematical function—for example, a parabolic curve—and typically does not exactly coincide with the street profile. The intersection's contour grading plan usually provides clues to the drainage pattern and the potential location of sump areas. An experienced engineer will design the intersection with drainage as a priority consideration. For example, locating an intersection within the low area of a vertical curve creates drainage design difficulties. Avoiding a very flat cross slope at or near the lowpoint of a sag vertical curve also facilitates the drainage design in the intersection area.

Often, local design criteria prescribe an upper limit to the amount of flow that can bypass an intersecting street. Typically, the amount of flow crossing the intersection depends on the functional street classification. The higher the functional classification, the lower the amount of discharge allowed to pass the intersection. Occasionally, design criteria may even prescribe that no flow can pass the intersection regardless of the street's functional classification; therefore, the inlet should be located at the ends of the curb returns. The designer should consider the location of any handicap ramps or pedestrian crossings prior to placing inlets at the end of the curb returns. Depending on the longitudinal street slope and the gutter flow, an inlet just upstream of this location may also be necessary. Locating inlets at the ends of curb returns also reduces flows around the curb returns, which may be a consideration if the longitudinal gradient of either street is very steep or if the area is a high-pedestrian-traffic area.

It is difficult to install curb inlets in curb returns with short radii. Therefore, the engineer may decide to show the profile of the curb return to ensure no sump area exists and to guide the contractor that is installing the curb return. Inlets with relatively short throats or short grates may be installed on curb returns with larger radii without disrupting the continuity of the curve. Occasionally, curb returns of large radii (e.g., 100 feet or more) that are longer than normal may be designed to intentionally have a sump area to keep runoff from spilling into the travel area of the intersection.

After inlets have been placed at the required locations, the location of any and all remaining inlets is dictated by the

[1] A superelevation transition is a segment of the road used to gradually change the cross slope of the pavement from a normal crown section (straight section of road) to a superelevation section (curved section of road, like a racetrack curve that is banked), and vice versa.

[2] The term *false low point* is used to indicate a low-point location difference from the low-point location given on the PGL.

limitations on spread of flow into the street. Frequently, the inlet is intentionally sized to intercept less than the total design flow approaching the inlet, thus allowing some flow to carry over and be added into the design discharge for the next downstream inlet. One study concludes that an inlet's capacity is maximized if some water is permitted to bypass the inlet. Therefore, the size and location of street inlets on grade depends on how the design discharge in the street is divided among the inlets.

In parking areas, the grading plan determines the drainage pattern and inlet location. In commercial building sites, pedestrian traffic is an important consideration for grading and drainage. Sump areas should be avoided in pedestrian travel ways such as crosswalks or near entrances to the building. Additionally, sump areas should be avoided in areas where passengers discharge from vehicles such as bus stops or walkways. Although there is typically no limitation for the spread of flow into privately maintained travel lanes and parking areas, good judgment is needed to limit the spread in cold regions, since the formation of ice sheets is a concern. Handicap ramps and parking spaces also need to be considered when locating drainage inlets and sump areas.

Location of Inlets Outside of Paved Areas

The drainage system should be carefully integrated into all projects. Ideally, the drainage system should accommodate the site or roadway engineer's plan, and not be the driving factor behind the remaining design components. In single-family detached projects, drainage patterns favor the rear and side of the houses. Swales and inconspicuous ditches convey the water across the rear of the lots. The rate of flow being conveyed across a lot is limited to nonerosive velocities. No more than 2 to 4 cfs should concentrate and flow across the lots without being intercepted or conveyed in a well-defined and stabilized channel. Maintenance and ownership of swales and ditches is a factor in drainage design in suburban developments. Drainage easements may be necessary. The desirability of a lot is reduced if a drainage easement runs through the middle of a rear yard. In most cases, the drainage system should be kept within the public right-of-way.

Manholes

Manholes are typically precast circular concrete barrel sections, in 3- to 4-foot lengths, that stack on top of each other. The elevation of the top of the manhole is adjusted to meet grade with spacer rings. The top is covered with an iron ring fitted with an iron cover. Manholes are used to change the horizontal and/or vertical direction of pipes, while also acting as a junction, allowing the convergence of several incoming pipes. Many types of inlets use the manhole barrel sections, but have a precast throat or grate that fits to the top instead of the frame and cover.

It is common practice to match crowns of an incoming and outgoing pipe. When several pipes converge at a manhole, matching crowns may not be feasible due to the width of the manhole, the diameters of the incoming pipes, and the angles of approach. The diameter of the manhole depends on the size of the pipes connecting to it. Standard manhole diameters are approximately 4 feet.

In Figure 21.12*a*, the size and angles of the pipes are such that they can be connected to the manhole without interfering with each other. Compare this to Figure 21.12*b*, where the pipe sizes and angles cannot fit into the manhole at the same elevations (or nearly the same elevations). In the second case, the elevations of the pipe should be staggered enough to provide for the necessary clearance. In each case, the thickness of the pipe walls should be considered when determining the necessary manhole size. Note: A rule of thumb for the wall thickness of a standard reinforced con-

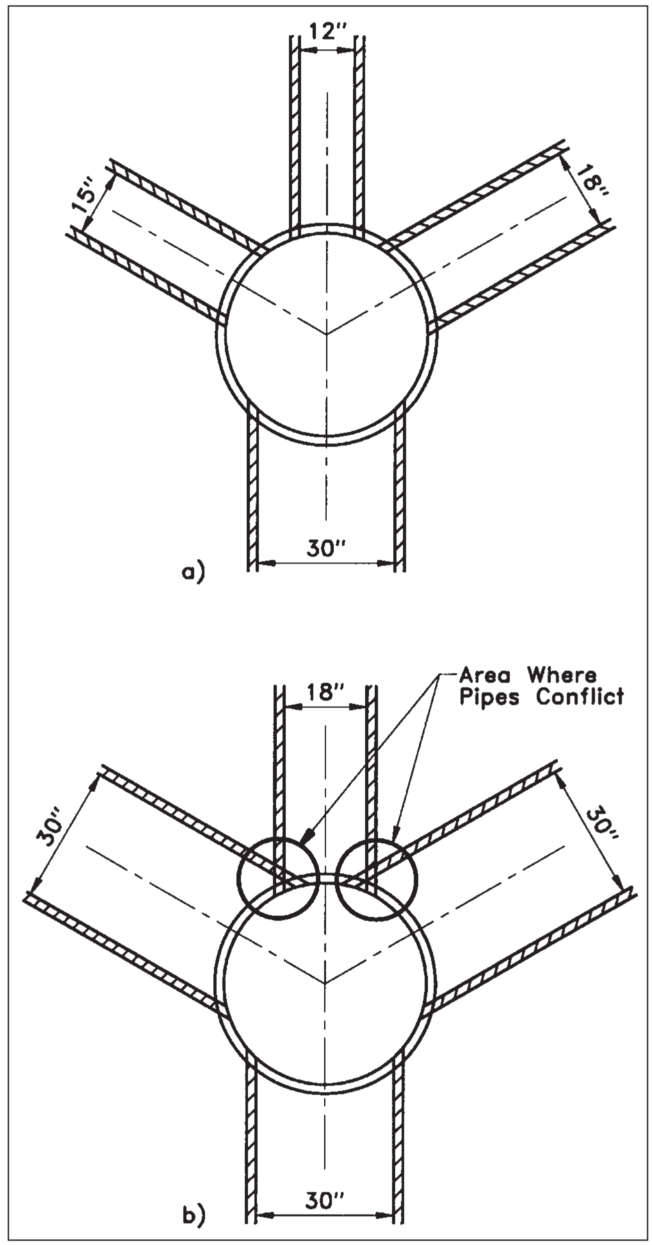

FIGURE 21.12 Pipes connecting at manhole at same elevation.

crete pipe is as follows. The wall thickness (in inches) is equal to the diameter of the pipe (in feet) plus 1. For example, a 48-inch pipe will have a thickness of 5 inches (4-foot diameter + 1).

Similar to the preceding discussion, where several pipe connections to the manhole must be checked for proper fit, the skew angle of the pipe connection at a rectangular structure must be checked for fit. Figure 21.13*a* shows an incoming 36-inch-diameter pipe properly fitted to a 3-foot by 5-foot (outside dimensions) structure. In Figure 21.13*b*, the pipes are skewed and do not properly connect to the structure. In this example, the center of the structure is aligned with the centerline of the pipe, and the skew angle causes part of the incoming pipe to overlap onto the 3-foot side of the structure.

In most moderate-density developments, manholes and inlet structures are spaced less than several hundred feet apart by necessity. Most localities set design criteria limiting the maximum distances between manholes, which often are a function of the pipe size. Table 21.3 is the recommended spacing provided by AASHTO. This distance is usually determined by maintenance and accessibility concerns; verify acceptable distances per locality.

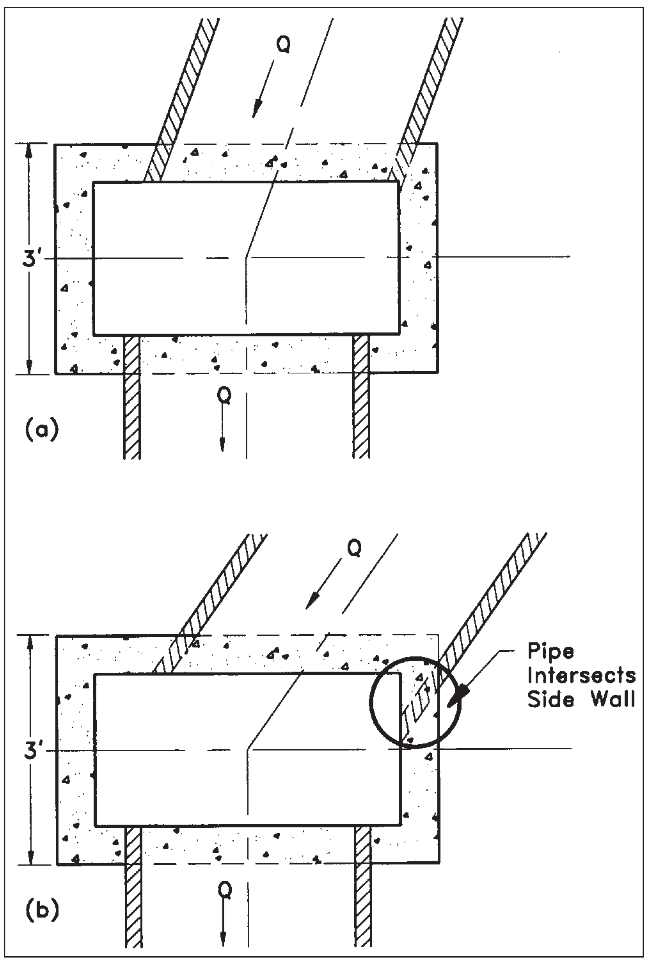

FIGURE 21.13 Skew angle for pipes connecting to rectangular structure.

TABLE 21.3 Recommended Manholes Spacing

Pipe Diameter	Distance (ft)
12–24	350
27–36	400
42–54	500
≥60	1000

Stormwater Management Considerations

Oftentimes, the storm sewer and pipe design of a roadway drainage system are governed by the need to convey water to a stormwater management (SWM) facility. SWM facilities can include large ponds, basins, infiltration areas, grassed swales, or other devices meant to reduce peak flow runoff or to treat runoff for water quality purposes. Much of the focus on today's stormwater management design, for roadway and land development projects, is on water quality. Therefore, even if the designer can provide the necessary detention or prove that detention requirements are not warranted, more than likely water quality requirements will still be required. Given the site constraints or the SWM needs required for the development, most storm sewer systems and inlets are driven by the need to collect runoff and discharge it into an SWM facility.

With the growing demand for re-development and the emphasis on water quality, numerous manmade structures are being used to provide water quality. There are a variety of water quality inlets that help to remove oil, grit, sediment, and pollutants. Many of these devices are underground structures varying in size (from regular-sized manholes to large-vault boxes) that are connected directly to a storm sewer system. Given the amount of flow or drainage area accumulated in a storm sewer system, the engineer may decide to design a system that diverts a portion of the runoff to a water quality inlet. This will divert the first flush of the stormwater (in theory, the runoff with the most pollutants) into the water quality inlet, while allowing the remainder of the stormwater to flow through the pipe system. When stormwater is diverted within a system, the water quality inlet is said to function off-line. When the water quality inlet is placed within the storm sewer system itself (usually on small catchment areas only), the system is considered to be on-line.

Pipe Design

After inlet locations and sizes are established, the pipe conveyance system is determined. The pipe network typically converges to the outfall point. Occasionally, due to site conditions, the network is separated into several systems, each discharging at a different outfall point or connecting to another storm sewer network. Outfall points can be natural channels of adequate capacity, retention/detention areas, lakes, and rivers. The size, slope, and depth of the pipe in the network are controlled by the elevation of the outfall point. This is more of a problem in flat terrain than in rolling or hilly terrain. In flat terrain, the engineer may have design problems trying to match outfall elevations, whereas in steep terrain, high velocity and high-energy losses may create a potential problem. In general, the slope and size of the pipe are kept to the minimum required to carry the design flows at near full capacity, which helps ensure proper cleanout of the storm sewer systems. Recognize, however, that many public agencies have a requirement for a minimum allowable pipe size and slope. For storm sewer systems in steep terrain, the minimum pipe size may have excess capacity.

The pipe network, wherever possible, should be located within the public right-of-way. Most storm sewer systems are maintained by a government agency. Therefore, any part of the conveyance system on private property, requires an easement to allow access. Additionally, it is desirable to locate the pipe parallel to a property line, offset to one side. This allows for maximum use of the property (i.e., no encumbrances through the middle of the lot) and also allows an owner to build a fence without having to dismantle it, if the pipe needs to be repaired.

Common practice is to set the pipe at minimum depth (i.e., minimum cover or minimum inlet depth) or at the shallowest depth possible (to ease in constructability) and select the pipe size and slope that convey the design discharge at near full capacity. The pipe network is typically designed such that the HGL is at or below the crown of the pipe (i.e., nonpressure flow). Under such conditions, the pipe network is surcharged for storms that generate runoff greater than the design storm. The HGL should be checked against this secondary, or check, storm—the local design standards may even require it. The designer should determine the overland relief path for the larger secondary storm surcharges for safety or property damage concerns. Site grading or alignment, which would result in these surcharges damaging private property, should be rethought.

Discharge velocity in a pipe should be kept within a nominal range to prevent scour and eliminate sediment buildup. Although efforts are made to keep sediment from entering the system, all sediment cannot be kept out. Sediment transported by very high velocities causes abrasion damage to the pipe. Low velocities cause sediment to settle out and reduce the pipe capacity. A recommended velocity range is 2 to 12 feet per second (fps).

Avoiding conflicts with other underground utilities is a major objective in the design of a storm sewer system. Since storm sewer flow is driven by gravity, any conflicts with other proposed non-gravity-dependent utilities are usually resolved by redirecting those utilities. Attempts are made to locate the proposed storm sewer system around any existing gravity or non-gravity-dependent utilities. It can be costly to redirect existing utilities, and only in the unavoidable case is this done.

Pipe Materials

Pipes can be manufactured from many different materials, including concrete, reinforced concrete, aluminum, steel, and various other synthetic materials. Some of the synthetic materials, such as high-density polyethylene (HDPE) pipe, come in smooth lines or corrugated, depending on engineering needs. HDPE pipe has become a favorite among developers due to the material and installation costs. It is important to determine the availability of pipe material selection per locality specifications and site constraints. The pH level and resistivity of the soil, whether it is a high- or low-fill area, corrosive environmental conditions, and tidal areas are some of the site constraints. Others may be the preference of contractor, the proximity to manufacturing plants, and the cost of the different pipe materials—the engineer must be careful to consider the pipe material when designing a storm sewer system. The various different pipes available on the market can have an enormous range of n values (from as little as 0.007 to as high as 0.033). Since n value plays an important role in pipe capacity and hydraulic grade line calculations, the selection of the pipe material could dramatically affect the design.

Some localities provide guidance on the types of materials preferred. Many other jurisdictions allow the contractor to choose the pipe material. When the contractor is given the option of pipe materials, it is up to either the contractor or the engineer to determine whether the material selected still meets the design requirements of the construction documents. Therefore, it is important that the engineer understand the requirements of the local industry before determining pipe materials to be used for design and analysis.

Underdrain Design

The inlet and storm sewer design focused on drainage pavements, which have surface water runoff. However, there are many instances where water collects underneath the pavement section, either in locations of cut/fill transitions or just by infiltration. Water usually collects in the subgrade portion of the pavement, especially in areas where aggregate or stone is used in the design. This collection of water underneath the pavement can be extremely problematic, leading to loss of stability and strength of the pavement structure, fatigue based on freeze/thaw conditions, or loss of cohesion and bearing pressures of the surrounding soil.

Given certain situations, this excess water underneath the pavement requires that a secondary drainage system be constructed to reduce the water collected underneath roadways. This is usually done by placing a combination of small plastic pipes (sometimes perforated or wrapped in geotextile fabric) along the aggregates section of the pavement box and discharging the water into either a ditch or a structure (i.e., inlet or manhole) associated with the roadway drainage system. These devices are called *underdrains*.

In most urban situations, underdrains are placed along the edge of the pavement, below the curb and gutter section.

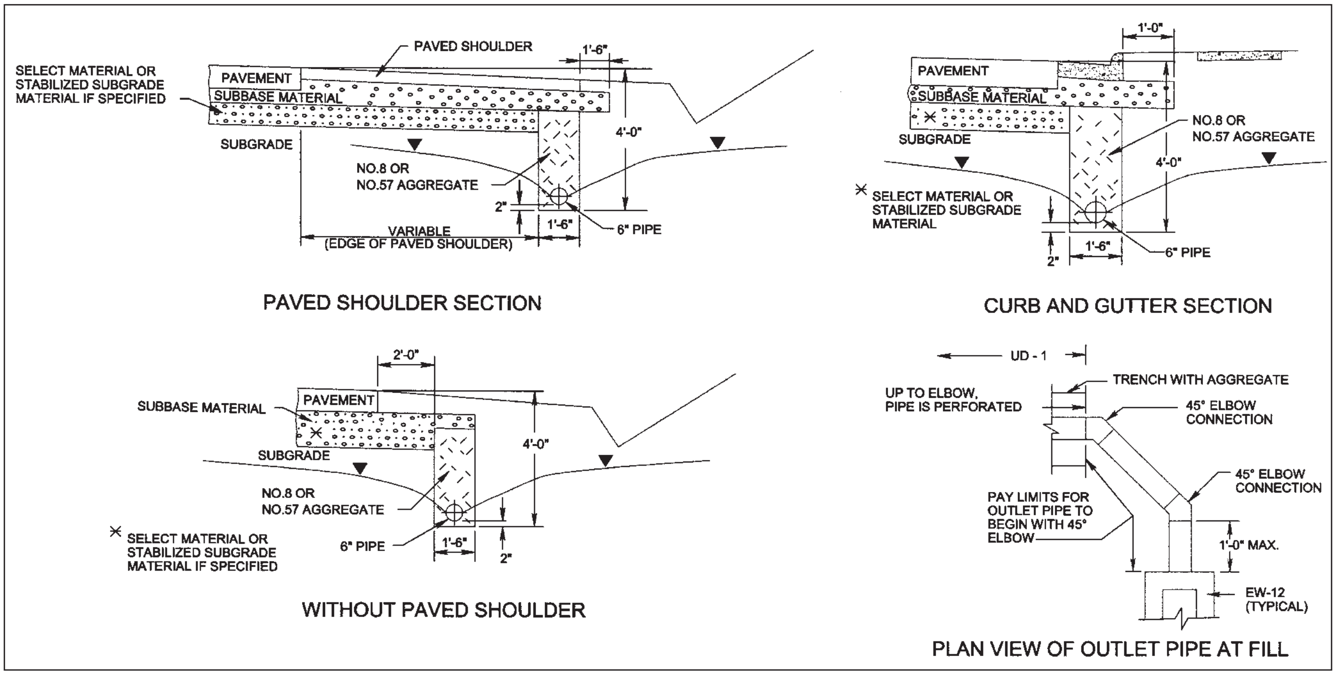

FIGURE 21.14 Typical underdrain.

Typical roadway design requires that the pavement be sloped to the edge to facilitate drainage. The same applies to pavement design as well, such that all layers of the pavement box (top surface coarse, base coarse, subgrade, etc.) drain to the outside. Curb and gutter sections typically are constructed on stone or aggregate bases, meaning that water can flow easily along the corridor. Underdrains placed longitudinally below the curb line, within the aggregate, can capture the majority of water trapped beneath the pavement and discharge it directly into the roadway drainage system. Figure 21.14 shows a typical underdrain.

OPEN CHANNEL FLOW IN PIPES AND CHANNELS

The two basic forces that act on flow in an open channel are gravity (pulling it downward) and friction (retarding its movement). These factors then have to be combined with the basic concept of continuity, which is that the flow in one discrete section of channel or pipe must equal the flow out of that section. This is the basic premise for estimating open channel flow in channel and pipes. Therefore, open channel flow Q is estimated by combining the continuity equation $Q = VA$ with Manning's equation for velocity.

$$Q=\left(\frac{1.49}{n}\times R^{2/3}S^{1/2}\right)\times A \qquad (21.19)$$

where the term in parentheses represents Manning's velocity for open channel flow. In Equation 21.19, n = Manning's coefficient of roughness; R = hydraulic radius (ft), defined as the ratio of the cross-sectional area to the wetted perimeter; S is the slope of the energy grade line (ft/ft); and A is the cross-sectional area of the flow (ft^2). In the equation, the term in parentheses represents the velocity of flow as per the Manning equation. Natural conveyance systems (i.e., swales, ditches, and channels) are increasingly popular in residential applications and/or slower-speed roadway environments. Natural channels are subject to the same theories reviewed in open channel flow; however, they are discussed more thoroughly in the "Stormwater Management Considerations" section, as they have additional benefits beyond just conveyance that are more relevant to quantity/quality control.

The crosshatched area of Figure 21.15 shows the cross-sectional area of flow for a circular section and a trapezoidal section. The wetted perimeter for the circular section is arc ABC. Line segments ABCD show the wetted perimeter on the trapezoidal section.

The roughness coefficient represents an estimate of the resistance of flow. Large n values correspond to high resistance to flow. Table 21.4 provides n coefficients for commonly occurring channel materials.

Following are some of the factors that affect flow resistance:

- Surface roughness, due to size and shape of the grains of the material forming the wetted perimeter, increases the roughness coefficient as the coarseness of the grains increases.
- Vegetation is also a form of surface roughness. The degree to which vegetation impacts flow resistance depends on density, height, and type of vegetation.
- Channel irregularities such as those found in natural streams. Channel irregularities include depressions in the channel bed, humps, sandbars, ridges, and so on, which change the wetted perimeter size and shape of

cross section. Abrupt channel changes have a larger effect on the *n* value than small or gradual irregularities.

■ Channel alignment and curvature have some impact on flow resistance. A large radius of curvature has less effect than a short radius.

■ Obstructions such as logs, stumps, debris, trash, rocks, and other items that interrupt and severely alter the flow path increase the flow resistance.

In a circular pipe flowing full with diameter *D,* the hydraulic radius is *D*/4. In a pipe flowing less than full, the relationship between depth *y,* cross-sectional flow area *A,* wetted perimeter *P,* and hydraulic radius *R* is illustrated in Figure 21.16 and given by the following:

$$y = \frac{D}{2}(1 - \cos\theta) \qquad (21.20)$$

$$A = \frac{D^2}{4}(\Theta - \sin\Theta\cos\Theta) \qquad (21.21)$$

$$= \frac{D^2}{4}(\Theta - 1/2\sin 2\Theta)$$

$$P = D\Theta \qquad (21.22)$$

$$R = \frac{A}{P} = \frac{D}{4}\left(1 - \frac{\sin\Theta\cos\Theta}{\Theta}\right) \qquad (21.23)$$

which simplifies to

$$R = \frac{D}{4}\left(1 - \frac{\sin 2\Theta}{2\Theta}\right)$$

Energy Losses in Pipe Systems

Flow in a conduit is retarded by resistance and turbulence. Resistance and turbulence are measured in terms of the energy consumed to overcome them, which is mostly in the form of frictional losses along straight sections of the conduit. Turbulence is also created where there is an abrupt change in cross section of the flow (e.g., sudden contraction or sudden expansion) or by other interferences of the flow. The concept of uniform flow in open channels is a balance between the available energy that is generated by gravity and the consumed energy of the flow resistance.

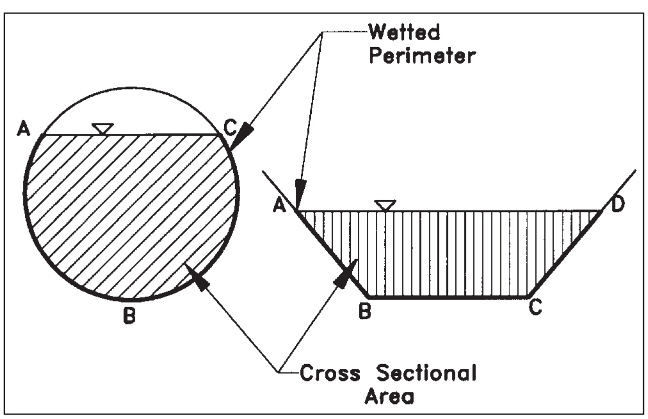

FIGURE 21.15 Cross-sectional area and wetted perimeter for circular section and trapezoidal section.

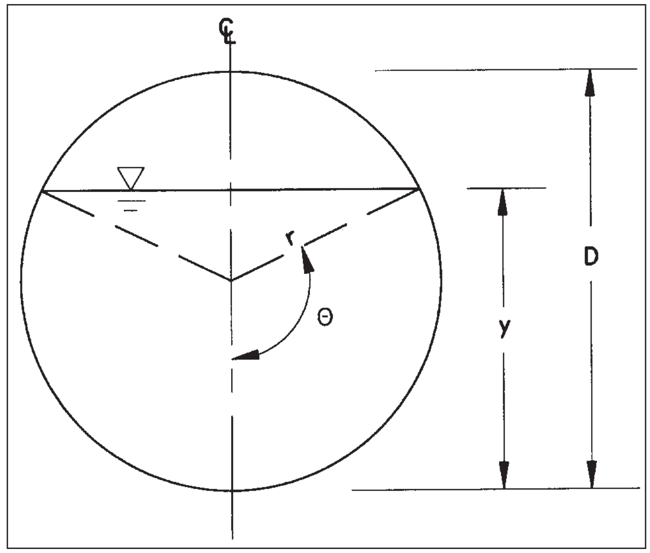

FIGURE 21.16 Nomenclature for pipe flowing partially full.

Uniform flow occurs whenever the depth, water area, velocity, and discharge at every section in a channel reach remain constant. For such stringent conditions to exist, not only must channel geometry be consistent, but the drop in potential energy (due to the fall in elevation in the channel bed) must be equal to the energy consumed through boundary friction and turbulence. Hence, if the channel geometry and slope remain constant and the reach is sufficiently long, then for a given discharge there will exist one, and only one, depth at which the flow will be uniform. This depth is referred to as *normal depth.*

The energy at a particular location in a pipe is given by Bernoulli's equation:

$$E = \frac{p}{\gamma} + \frac{V^2}{2g} + z \qquad (21.24)$$

where p/γ is the pressure head,[3] $V^2/2g$ is the velocity head, and *z* is the elevation head. A plot of points given by Equation 21.24 at every section along a length of a pipe is known as the *energy grade line* (EGL). By utilizing the conservation of energy principle along with the Bernoulli equation, the energy at point B, downstream of A, is less than the energy at point A by an amount equal to the energy lost between points A and B. Mathematically, this is expressed as:

$$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + z_A = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + z_B + \Sigma h_L \qquad (21.25)$$

[3]In hydraulics, the term *head* is synonymous with energy.

TABLE 21.4 Values of the Roughness Coefficient *n*

Type of Channel and Description	Minimum	Normal	Maximum
A. Closed Conduits Flowing Partly Full			
A-1. Metal			
a. Brass, smooth	0.009	0.010	0.013
b. Steel			
1. Lockbar and welded	0.010	0.012	0.014
2. Riveted and spiral	0.013	0.016	0.017
c. Cast iron			
1. Coated	0.010	0.013	0.014
2. Uncoated	0.011	0.014	0.016
d. Wrought iron			
1. Black	0.012	0.014	0.015
2. Galvanized	0.013	0.016	0.017
e. Corrugated metal			
1. Subdrain	0.017	0.019	0.021
2. Storm drain	0.021	0.024	0.030
A-2. Nonmetal			
a. Lucite	0.008	0.009	0.010
b. Glass	0.009	0.010	0.013
c. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
d. Concrete			
1. Culvert, straight and free of debris	0.010	0.011	0.013
2. Culvert with bends, connections, and some debris	0.011	0.013	0.014
3. Finished	0.011	0.012	0.014
4. Sewer with manholes, inlets, etc., straight	0.013	0.015	0.017
5. Unfinished, steel form	0.012	0.013	0.014
6. Unfinished, smooth wood form	0.012	0.014	0.016
7. Unfinished, rough wood form	0.015	0.017	0.020
e. Wood			
1. Stave	0.010	0.012	0.014
2. Laminate, treated	0.015	0.017	0.020
f. Clay			
1. Common drainage tile	0.011	0.013	0.017
2. Vitrified sewer	0.011	0.014	0.017
3. Vitrified sewer with manholes, inlet etc.	0.013	0.015	0.017
4. Vitrified subdrain with open joint	0.014	0.016	0.018
g. Brickwork			
1. Glazed	0.011	0.013	0.015
2. Lined with cement mortar	0.012	0.015	0.017
h. Sanitary sewers coated with sewage slimes, with bends and connections	0.012	0.013	0.016
i. Paved invert, sewer, smooth bottom	0.016	0.019	0.020
j. Rubble masonry, cemented	0.018	0.025	0.030

TABLE 21.4 (*Continued*)

Type of Channel and Description	Minimum	Normal	Maximum
B. Lined or Built-up Channels			
B-1. Metal			
a. Smooth steel surface			
1. Unpainted	0.011	0.012	0.014
2. Painted	0.012	0.013	0.017
b. Corrugated	0.021	0.025	0.030
B-2. Nonmetal			
a. Cement			
1. Neat, surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
b. Wood			
1. Planed, untreated	0.010	0.012	0.014
2. Planed, creosoted	0.011	0.012	0.015
3. Unplaned	0.011	0.013	0.015
4. Plank with battens	0.012	0.015	0.018
5. Lined with roofing paper	0.010	0.014	0.017
c. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Finished, with gravel on bottom	0.015	0.017	0.020
4. Unfinished	0.014	0.017	0.020
5. Gunite, good section	0.016	0.019	0.023
6. Gunite, wavy section	0.018	0.022	0.025
7. On good excavated rock	0.017	0.020	
8. On irregular excavated rock	0.022	0.027	
d. Concrete bottom bloat finished with sides of			
1. Dressed stone in mortar	0.015	0.017	0.020
2. Random stone in mortar	0.017	0.020	0.024
3. Cement rubble masonry, plastered	0.016	0.020	0.024
4. Cement rubble masonry	0.020	0.025	0.030
5. Dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of			
1. Formed concrete	0.017	0.020	0.025
2. Random stone in mortar	0.020	0.023	0.026
3. Dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. Glazed	0.011	0.013	0.015
2. In cement mortar	0.012	0.015	0.018
g. Masonry			
1. Cemented rubble	0.017	0.025	0.030
2. Dry rubble	0.023	0.032	0.035
h. Dressed ashlar	0.013	0.015	0.017
i. Asphalt			
1. Smooth	0.013	0.013	
2. Rough	0.016	0.016	
j. Vegetal lining	0.030	—	0.500

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where the Σh_L term accounts for the total energy lost between points A and B.

The energy gradient (hydraulic slope) is defined as the energy loss per length of channel:

$$S = \frac{h_L}{L} \tag{21.26}$$

In closed conduits under pressure flow, the potential energy plus the pressure energy in the system is given as $z + P/\gamma$. This term, also referred to as the *static head* or *piezometric head,* represents the level to which the liquid will rise if a piezometer tube were installed at this location. A continuous line drawn through the tops of these piezometer columns is the *hydraulic grade line* (HGL). In open channel flow, the water surface itself is the hydraulic grade line. In uniform flow, the slope of the channel, the slope of the water surface, and the slope of the hydraulic gradient are all parallel.

Head loss is attributed to pipe friction, abrupt changes in the cross-sectional area (due to entrance and exit of flow to or from a reservoir or manhole), or other types of appurtenances and obstructions within the flow path. The two most commonly used friction loss equations for determining hydraulic resistance are the Darcy equation and the Manning equation. The Darcy-Weisbach equation is given as:

$$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right) \tag{21.27}$$

where h_f = friction energy loss, f = Darcy-Weisbach friction factor, L = length of conduit, D = diameter of the conduit, V = mean velocity in the conduit, and g = gravitational acceleration.

The Darcy-Weisbach friction factor is obtained from the Moody diagram (see Figure 25.33), which relates f to the Reynolds number and the relative roughness of the conduit.[4] Conversion of the Darcy-Weisbach friction factor f to the Manning roughness coefficient n is given by:

$$n = 0.0926\, R^{1/6} f^{1/2} \tag{21.28}$$

where R is the hydraulic radius.

In the Manning equation, the slope of the energy line S is given as $S = h_f/L$, where h_f is the friction loss and L is the length of conduit. Substituting for S and solving for h_f in the Manning equation gives:

$$h_f = \left(\frac{29\, n^2 L}{R^{4/3}}\right)\frac{V^2}{2g} \tag{21.29}$$

In addition to pipe friction energy losses, there are minor energy losses through manholes, bends, and other appurtenances. Energy losses through such appurtenances are proportional to the velocity head in the appurtenance and are accounted for as follows:

$$h_L = k\,\frac{V^2}{2g} \tag{21.30}$$

where k is an empirical coefficient that accounts for the energy loss for a particular appurtenance or configuration. Table 25.13 gives k values for various conditions).

Minor energy losses through manholes and junctions are the result of the deflection angle of the flow, entrance losses as the flow enters the discharge pipe from the manhole, and exit loss as the flow leaves the incoming pipe. As indicated by Equation 21.30, high velocities result in high energy losses. However, the energy loss through the manhole can be significantly reduced through inlet shaping. Inlet shaping provides a flow trough at the bottom of the manhole to direct the flows from the incoming pipes to the downstream pipe. Exit loss coefficients, energy loss coefficients, and other loss coefficients are typically identified in the local standards criteria. Figure 21.17 gives some values for k as prescribed by the American Association of State Highway and Transportation Officials (AASHTO).

In addition, losses for deflection of flows from the incoming pipes to the outgoing pipe have to be considered. When a junction or manhole has more than one incoming pipe, each pipe is analyzed for the total head loss of the combined effects (entrance, exit, deflection, etc.). The pipe producing the greatest head loss is assumed to be the controlling pipe, and the EGL and HGL are based on this greatest value.

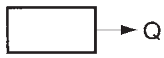
Energy losses also occur at inlets that collect surface runoff and discharge directly into the storm sewer system. The water dropping into the bottom of the manhole produces turbulence within the water that is already flowing through the manhole, thus disturbing (even further) the flow from the upstream pipes. These energy losses are added to the conventional losses attributed to the exit and entrance losses from the discharge ends of the incoming pipes. Other losses, which are less frequently encountered in the pipe network, include diffusor/confusor losses, losses associated with converging or diverging wyes, and bends. Figure 21.17 summarizes the various minor energy losses through structures.

Hydraulic Grade Line in Pipe Systems

Most storm sewers are intended to operate as gravity flow for the design discharge. Occasionally, due to unavoidable field conditions such as high flow rates or low-lying flat areas where little fall is available, the system is surcharged (i.e., operates as pressure flow). Even though the pipes were sized to function under gravity flow, accumulated head losses can cause surcharge in the system if, during design, sufficient allowances were not made to compensate for the accrued head losses. Surcharge in the system occurs when the hydraulic grade line rises above the crown of the pipe.

Most localities prefer the storm drainage system to operate as gravity flow for the design discharge. However, surcharge of the system for the design flow is tolerable if the hydraulic grade line is maintained below a certain limit. Typically, this is a specified distance above the crown of the pipe

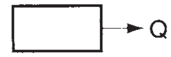
[4]The Reynolds number is a dimensionless parameter that is a ratio of inertial forces to viscous forces. Relative roughness is the ratio of element roughness size to conduit size. Consult basic hydraulic texts for further discussion.



$$H_{tm} = \frac{V^2}{2g} \qquad \textbf{(a)}$$

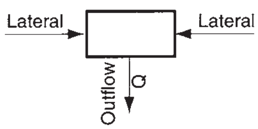
Terminal Junction Losses
(at beginning of run)

Where g = gravitational constant, 32.2 feet per second per second



$$H_e = 0.5\frac{V^2}{2g} \qquad \textbf{(b)}$$

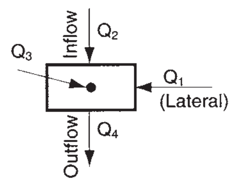
Entrance Losses
(for structure at end of run)
Assuming square-edge



$$H_{j1} = \frac{V^2}{2g}\text{ (Outflow)} \qquad \textbf{(c)}$$

Junction Losses

Use only where flows are identical to above, otherwise use H_{j2} Equation.

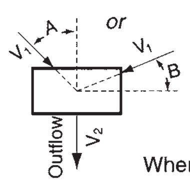


$$H_{j2} = \frac{Q_4V_4^2 - Q_1V_1^2 - Q_2V_2^2 + KQ_1V_1^2}{2gQ_4} \qquad \textbf{(d)}$$

Junction Losses
(After FHWA)

Total losses to include H_{j2} plus losses for changes in direction of less than 90° (H_b).

Where K = Bend loss factor
Q_3 = Vertical dropped-in flow from an inlet
V_3 = Assumed to be zero



Where B = 90 - A

$$H_b = \frac{KV_1^2}{2g} \qquad \textbf{(e)}$$

Bend Losses
(changes in direction of flow)

Where K	Degree of Turn (A) in Junction
0.19	15
0.35	30
0.47	45
0.56	60
0.64	75
0.70	90

Friction Loss (H_f)

$$H_f = S_f \times L \qquad \textbf{(f)}$$

Where H_f = friction head
S_f = friction slope
L = length of conduit

$$S_f = \left(\frac{Qn}{1.486\,AR^{\frac{2}{3}}}\right)^2$$

Where Q = discharge of conduit
n = Mannings coefficient of roughness (use 0.013 for R.C. pipes)
A = area of conduit
R = hydraulic radius of conduit ($^D/_4$ for round pipe)

Total Energy Loss at Each Junction

$$H_T = H_{tm} + H_e + (H_{j1} \text{ or } H_{j2}) + H_b + H_f$$

FIGURE 21.17 Summary of energy losses through structures.

PROJECT: ______________________ DESIGNED BY: ____________ CHECKED BY: ____________

DESIGN STORM: ______________________ DATE: ____________ DATE: ____________

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
				Friction Loss in Pipe						Terminal Structure Losses		Junction Losses									
Struct. No.	D/S EGL	h_v out	D/S HGL	D in	Q cfs	V fps	L ft	S_f ft/ft	H_f ft	H_{ex} ft	H_{entr} ft	H_0 ft	H_1 ft	H_b ft	H_T ft	1.3 H_T ft	0.5 H_T ft	U/S EGL	h_v in ft	U/S HGL	Rim Elev.

Column
1 Structure identification label
2 EGL elevation at downstream side of structure = preceding column 19 + preceding column 10
3 Velocity head at the discharge side of the structure = $V^2/2g$
4 HGL elevation = column 2 − column 3
5 Pipe diameter
6 Discharge
7 Discharge velocity
8 Pipe length between structures
9 Friction slope = $\left(\dfrac{Vn}{1.49\,R^{2/3}}\right)^2$
10 Friction head loss = column 8 × column 9 (fig. 14.20-f)
11 Exit head loss at terminal structure on D/S end of run (fig. 14.20-a)
12 Entrance head loss at terminal structure on U/S end of run (fig. 14.20-b)

Column
13 Contraction head loss for outflow from a nonterminal structure = $k_{ex}(V^2_{out}/2g)$
14 Expansion head loss for inflow into nonterminal manhole = $k_{entr}(V_{in}^2/2g)$
15 Bend head loss due to deflection of flow through manhole (fig. 14.20-e)
16 Total head loss through the junction = column 13 + column 14 + column 15
17 Head loss for contributing flow from surface inlet = column 16 × 1.3 if surface discharge is greater than 10% of the mainline flow
18 Reduction in head loss of column 16 for inlet shaping = column 16 or column 17 × 0.5
19 EGL on the upstream side of the manhole structure = column 2 + column 11 or column 16, 17, or 18
20 Velocity head of the incoming pipe = $V_{in}^2/2g$
21 HGL on the upstream side of the manhole structure = column 19 − column 20
22 Elevation of top of manhole or inlet structure

FIGURE 21.18 Hydraulic grade line computation form.

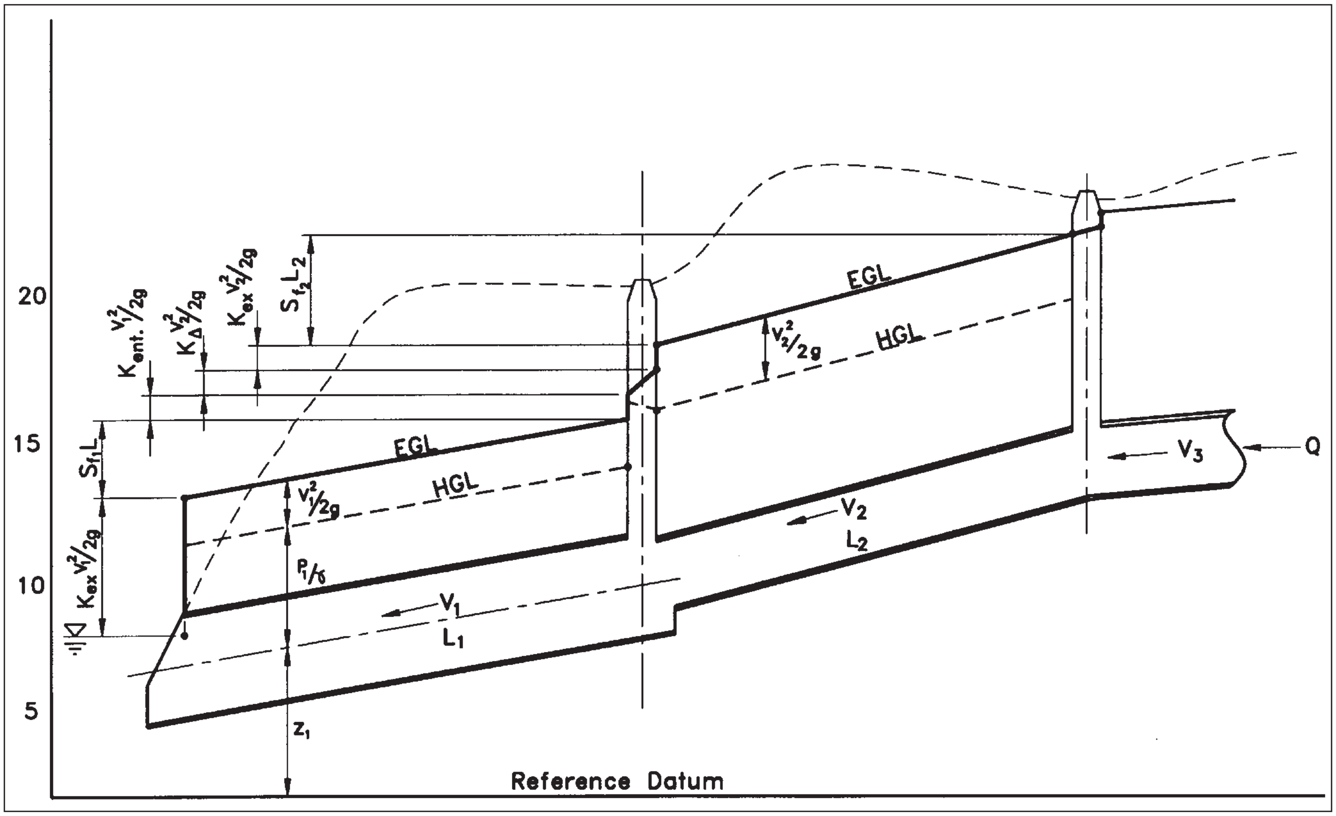


Figure 21.19 Schematic diagram for energy grade line and hydraulic grade line.

and below the ground surface elevation (e.g., the inlet inflow elevation or rim elevation). Some localities have developed criteria requiring the storm sewer system to be evaluated for specified storms larger than the design storm, such as in low-lying areas where there is little to no overland relief should runoff surcharge out of the system.

Hydraulic grade line calculations are easily summarized with the aid of an HGL calculation form as shown in Figure 21.18. The hydraulic grade line is parallel to and below the energy grade line along the length of conduit a distance equal to the velocity head $V^2/2g$. Energy losses through manholes and other appurtenances are graphically shown as abrupt jumps in the EGL. Figure 21.19 is a schematic representation of the HGL calculation form.

Computations for the HGL begin at a position where the water surface elevation is known or can be calculated. A known water surface elevation is where the HGL elevation can easily be determined, such as with the end of a pipe discharging into a lake. In this case, assuming the velocity head of the water at the lake's surface near the discharge end of the pipe is negligible, the starting EGL elevation is equal to the water surface elevation of the lake as well as the HGL of the lake. Should the end of the pipe discharge into a channel, the beginning water surface elevation can be found from backwater computations in the stream channel.

Once you have established the starting point, the computations proceed in the upstream direction by adding the energy losses attributed to exit, entrance, and junction losses to the EGL.

If storm sewer systems are assumed to operate with velocities in the 3–6-fps range, the HGL is approximated by the EGL. For normal velocities in the storm drain system, the difference between the EGL and the HGL elevations is less than 0.5 feet (i.e., for $V = 5$ fps, $V^2/2g = 0.4$ ft). Although the HGL is actually lower than the EGL by this amount, a relatively small velocity head is considered negligible, and many localities assume that the EGL approximates the HGL. A common design practice to anticipate and compensate for these velocity heads is to match crowns of the outgoing and incoming pipes of the manhole when the outgoing pipe is larger. If the two pipes are of equal size, common design practice would drop the outgoing pipe approximately 0.25 to 0.50 feet to account for losses that occur within the structure.

However, recognize that the occasion occurs, perhaps rarely, where such approximations can be substantially different. One case occurs when the discharge velocity in the incoming pipe is significantly greater than the velocity of the outgoing pipe in a manhole. This is illustrated at structure number 3 in the following example.

Example 3

Determine the HGL for the data given in Table 21.5.

All pipe is reinforced concrete pipe (RCP), $n = 0.015$. A plan/profile view of the pipe system is shown in Figure 21.20.

In this example, the water surface is known at the downstream side of structure 1. The head loss through

TABLE 21.5 Data for HGL/EGL Example 3

From	To	Diameter (in)	Length (ft)	Slope (ft/ft)	Discharge (cfs)
4	3	15	200	0.045	15
3	4	21	400	0.010	15
2	1	24	300	0.0075	21

the structure is computed to find the EGL on the upstream side. The head loss through the section of pipe is added to this to find the EGL on the downstream side of the next upstream structure. The process is repeated until the HGL falls below the crown of the pipe or until the end of the run. Detailed computations follow with reference to the HGL computation form shown in Table 21.6. The form is utilized best if each horizontal line is computed sequentially.

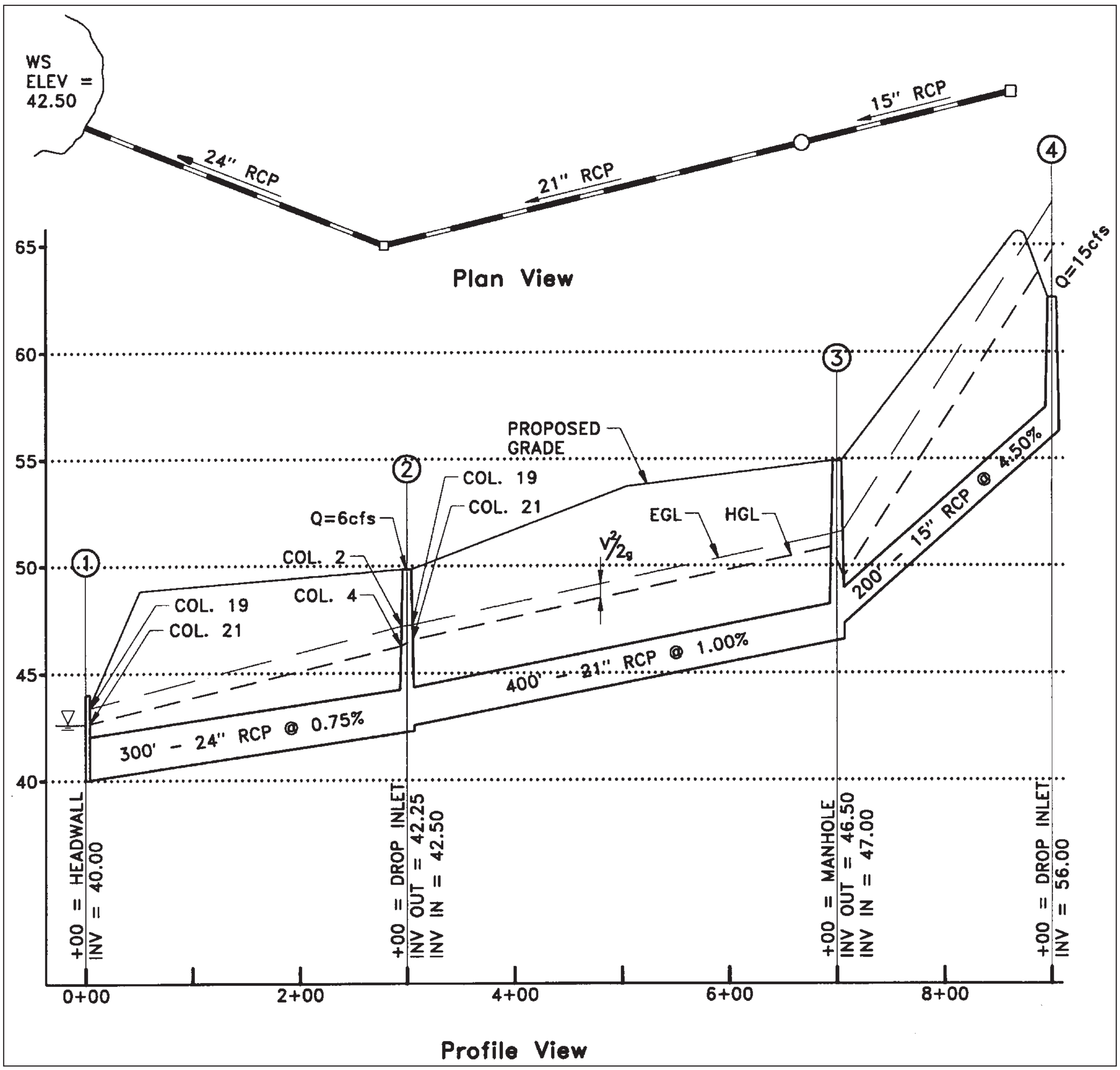


FIGURE 21.20 Plan and profile view of pipe system for Example 3.

TABLE 21.6 Hydraulic Grade Line Computation Form

PROJECT: EXAMPLE PROBLEM **DESIGNED BY:** ______ **CHECKED BY:** ______

DESIGN STORM: ______ **DATE:** ______ **DATE:** ______

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
				FRICTION LOSS IN PIPE						TERMINAL STRUCTURE LOSSES		JUNCTION LOSSES									
STRUCTURE No.	D/S EGL	H_v OUT	D/S HGL	D (IN.)	Q (CFS)	V (FPS)	L (FT)	S_T (FT/FT)	H_f (FT)	H_{ex} (FT)	H_{ent} (FT)	H_o (FT)	H_i (FT)	H_b (FT)	H_T (FT)	1.3 H_T (FT)	0.5 H_T (FT)	U/S EGL	h_v IN (FT)	U/S HGL	RIM ELEV.
1	42.50	0	42.50							0.69								43.19	0.69	42.50	
				24	21	6.69	300	0.011	3.30												
2	46.49	0.69	45.80									0.17	0.21	0.28	0.66	0.86	0.43	46.92	0.60	46.32	49.50
				21	15	6.24	400	0.012	4.80												
3	51.72	0.60	51.12									0.15	0.81		0.96		0.48	52.20	2.31	49.89	54.50
				15	15	12.2	200	0.072	14.3												
4	66.50	2.31	64.19								1.16						67.66		67.66	62.00	

Column
1 Structure identification label
2 EGL elevation at downstream side of structure = preceding column 19 + preceding column 10
3 Velocity head at the discharge side of the structure = $V^2/2g$
4 HGL elevation = column 2 − column 3
5 Pipe diameter
6 Discharge
7 Discharge velocity
8 Pipe length between structures
9 Friction slope = $(Vn/1.49\ R^{2/3})^2$
10 Friction head loss = column 8 × column 9 (Figure 21.17*f*)
11 Exit head loss at terminal structure on D/S end of run (Figure 21.17*a*)
12 Entrance head loss at terminal structure on U/S end of run (Figure 21.17*b*)
13 Contraction head loss for outflow from a nonterminal structure = $k_{ex}(V_{out}^2/2g)$
14 Expansion head loss for inflow into nonterminal manhole = $k_{entr}(V_{in}^2/2g)$
15 Bend head loss due to deflection of flow through manhole (Figure 21.17*e*)
16 Total head loss through the junction = column 13 + column 14 + column 15
17 Head loss for contributing flow from surface inlet = column 16 × 1.3 if surface discharge is greater than 10 percent of the mainline flow
18 Reduction in head loss of column 16 for inlet shaping = column 16 or column 17 × 0.5
19 EGL on the upstream side of the manhole structure = column 2 + column 11 or column 16, 17, or 18
20 Velocity head of the incoming pipe = $V_{in}^2/2g$
21 HGL on the upstream side of the manhole structure = column 19 − column 20
22 Elevation of top of manhole or inlet structure

Structure 1

Columns 2, 3, and 4. Structure 1 is a headwall with pipe discharging into a reservoir at water surface (WS) elevation = 42.5. The velocity of the water surface of the reservoir is assumed to be zero if we ignore the disturbance in the immediate vicinity of the headwall caused by the momentum of the incoming flow. The EGL at the downstream side of the headwall is:

$$\mathrm{EGL} = \frac{p}{\gamma} + \frac{V^2}{2g} + z \tag{21.31}$$

If, as assumed, $V = 0$, and we use gauge pressure as the reference, then $p/\gamma = 0$ and the EGL is equal to the water surface elevation z. Because $V = 0$, the HGL is also the water surface elevation (i.e., HGL = EGL − $V^2/2g$).

Column 11. Assume a loss coefficient k for a square-edged headwall = 1.0. The head loss through the headwall is:

$$H_{ex} = (k_{ex})\frac{V^2}{2g} = 1\left(\frac{6.69^2}{2g}\right) = 0.69 \text{ ft} \tag{21.32}$$

where V is the average discharge velocity in the pipe ($V = Q/A$).

Column 19. On the upstream side of the headwall, the EGL is equal to the EGL at the downstream side plus the head loss through the structure.

$$(U/S\ \mathrm{EGL})_1 = 42.50 + 0.69 = 43.19 \text{ ft} \tag{21.33}$$

Columns 20 and 21. The HGL at the upstream side of the headwall is equal to the EGL minus the velocity head in the pipe.

$$(U/S\ \mathrm{HGL})_1 = 43.19 - \frac{6.69^2}{2g} = 42.50 \text{ ft} \tag{21.34}$$

Columns 6 and 7. From Manning's equation, the maximum discharge through the 24-inch pipe is:

$$Q_{max} = \frac{1.49}{0.015}\left(\frac{2}{4}\right)^{0.67}(0.0075)^{0.5}\left(\frac{2^2\pi}{4}\right) = 17.0 \text{ cfs} \tag{21.35}$$

The pipe is carrying 21 cfs and is therefore under pressure, that is, the HGL is above the crown of the pipe. The velocity in the pipe is:

$$V = \frac{Q}{A} = \frac{21}{\frac{\pi\, 2^2}{4}} = 6.69 \text{ fps} \tag{21.36}$$

Columns 9 and 10. The friction slope of the water is:

$$S_f = \left(\frac{(6.69)(0.015)}{(1.49)\left(\frac{2}{4}\right)^{0.67}}\right)^2 = 0.011 \text{ ft/ft} \tag{21.37}$$

The total head loss in the 24-inch pipe is:

$$H_f = (0.011)(300) = 3.30 \text{ ft} \tag{21.38}$$

Structure 2

Columns 2, 3, and 4. The EGL on the downstream side of structure 2 is equal to the EGL on the upstream side of structure 1 plus the head loss in the pipe between structures 1 and 2.

$$(D/S\ \mathrm{EGL})_2 = 43.19 + 3.30 = 46.49 \text{ ft} \tag{21.39}$$

The HGL on the downstream side of structure 2 is one velocity head below the EGL.

$$(D/S\ \mathrm{HGL})_2 = 46.49 - \frac{6.69^2}{2g} = 45.80 \text{ ft} \tag{21.40}$$

Columns 13, 14, 15, and 16. The head loss through the structure is the combined effects from sudden contraction, sudden expansion, and momentum loss as the flow is deflected through the 45°. Proceeding in the upstream direction, the head loss due to sudden contraction as the flow leaves structure 2 and enters the pipe is:

$$H_o = k_o\left(\frac{V^2}{2g}\right) = 0.25\left(\frac{6.69^2}{2g}\right) = 0.17 \text{ ft} \tag{21.41}$$

The head loss for sudden expansion for incoming flow into structure 2 is:

$$H_i = 0.35\left(\frac{6.24^2}{2g}\right) = 0.21 \text{ ft} \tag{21.42}$$

The bend loss coefficient found in Figure 21.17 is 0.47. Using the incoming velocity,

$$H_b = 0.47\left(\frac{6.24^2}{2g}\right) = 0.28 \text{ ft} \tag{21.43}$$

The total head loss through the structure H_T = 0.17 + 0.21 + 0.28 = 0.66 ft. The head loss coefficients for sudden expansion and sudden contraction vary according to the standard design criteria of the local jurisdiction.

Column 17. Surface water entering through the top of the structure disrupts the flow in the mainline and thus creates head loss. The recommendation by AASHTO is to increase the total head loss through the structure by 30 percent to account for this additional head loss. This adjustment is applicable only for surface water entering the structure in the amount equal to or greater than 10 to 20 percent of the flow in the mainline of the pipe, based on local criteria. In this case, 6 cfs ≧ 0.1(15 cfs) and the adjustment is made; 1.3 (0.66) = 0.86 ft.

Column 18. Efficiency of flow through the manhole can be improved by constructing a trough through the bottom of the structure to direct the flow. This is known as *inlet shaping*. Most design standards for storm sewer manholes incorporate inlet shaping. If the storm sewer structure incorporates inlet shaping, the total head loss through the structure, in this case, is reduced 50 percent (this value varies according to local criteria). Column 16 (or column 17 for surface inlet structures) is decreased. For this structure, column 18 = 0.5(0.86) = 0.43 ft. However, hydraulic experts have questioned the effectiveness of inlet shaping for highly turbulent excessive surcharge flows.

Structure 3. Computations for structure 3 are similar to those for structures 1 and 2. Since structure 3 is a manhole-type structure and no surface water enters through the top, column 17 does not apply. Note that the EGL across structure 3 increases while the HGL decreases, due to the high incoming discharge velocity. This is one case where the HGL cannot be approximated to the EGL.

Structure 4. Structure 4 is a terminal structure and therefore only column 12 applies for computing the head loss. Notice the HGL elevation is above the rim elevation of the structure. This shows that for the given discharges and pipe design, the top of the structure is inundated by 3 feet of water. If the design discharges are for a frequent storm (i.e., recurrence interval ≤ 10 years) this pipe design, in all likelihood, would be unacceptable.

HGL Summary. HGL computations are vital to the proper design and construction of storm sewer systems. Keep in mind that the method described in the previous sample problem is typical; however, many localities have additional or different techniques. Some localities allow head losses at junctions to be reduced by inlet shaping, as suggested by column 18 in the HGL spreadsheet, while others do not. Some state departments of transportation also take conservative approaches to bend losses and junction losses, so always consult the local design criteria if available.

Another conservative approach practiced by many agencies is to assume that the minimum depth of the HGL along a pipe at the junction location (going upstream) can be no lower than a certain depth in the pipe, such as normal depth of $(D_c + D)/2$. For example, if calculated junction losses show that the elevation of the HGL is near the bottom of the upstream pipe, the user would start the HGL for the upstream pipe at $(D_c + D)/2$, not the calculated HGL value.

PROCEDURE FOR STORM SEWER DESIGN

Storm sewer is generally a gravity-based system (rather than pressurized): successful design is contingent upon thorough understanding of the outfall conditions, the contributing watershed characteristics (size, topography, land use, soils), and hydrology (discussed in Chapter 19). One of the more frustrating predicaments encountered by designers, after painstakingly designing the system, is to find that the design pipe invert elevation at the outfall point is too low. This can be avoided if preliminary pipe sizes are set based on rough estimates of the discharge and the first iteration of design is only a rough estimate. The general procedure for designing the storm sewer system is summarized as follows.

Data Collection

Obtain a plan of the project area showing existing and proposed features along with the existing topography and proposed grading. Profiles of roads, water and sanitary lines, invert elevations of the outfall points, topographic maps showing areas contributing off-site runoff and discharges from pipes, and typical sections of stream channels are all necessary information when designing the storm sewer system. This information should be assembled as part of the preliminary engineering efforts.

Evaluate Sump Inlet Locations

Inlets are set at all sump areas in streets, parking areas, and in nonpaved areas. Check all curb returns for low points. Using topographic information, establish the drainage areas to each inlet and compute the runoff. Include runoff and discharge from any areas outside of the project area. Use the appropriate capacity charts for the selected inlet to determine the ponding depth and/or spread at the inlet.

Supplementary Sump (Flanking) Inlets

If the inlets at the sump areas are inadequate either increase the size of the inlet or add another inlet upstream from the sump. If dual flanking inlets are not required such as recommended by FHWA, consider whether only one flanking inlet is necessary to reduce the ponding and spread in the sump. Similarly, if the drainage area on one side of the sump contributes most of the runoff, then consider only one flanking inlet. In residential areas, inlets should be located where they will not interfere with driveway entrances. In many cases final house and driveway locations are not known during the design of the storm sewer system. Usually, houses are centered on the lot and the driveway favors one side of the house. If the length of the flanking inlet is short, its location can be either the center of the lot or at the lot line extended. For longer-length inlets, the engineer must exercise judgment in anticipating the driveway location to locate the inlet. Inlets are considered in residential yards when the discharge velocity in the swale approaches erosive velocities or if flow depths are excessive. Few residents use the yard during a rainstorm; however, in poorly drained soils ponding and residual sogginess are a nuisance.

Other Inlet Locations

Other critical areas that warrant consideration are street intersections and curb returns. Many localities limit the amount of discharge that may cross through the entrance of an intersecting street. The amount of discharge may vary according to the functional designation of the street. Too much discharge flowing around a curb return causes the water to spread out as it moves around the curb. In lieu of any local restrictions, the engineer should consider adding inlets at curb returns to reduce the flow across the intersection when flows approach 3 to 4 cfs on lower-category streets and when flows are greater than 2 cfs on higher-category streets.

Placement of other inlets is then dictated by the spread limitations identified by design standards. Studies have shown that the efficiency of an inlet is increased if it is sized such that 5% to 10% of the flow is allowed to bypass. Therefore, consideration should be given for sizing the throat lengths so that they are about 90 percent efficient. In the

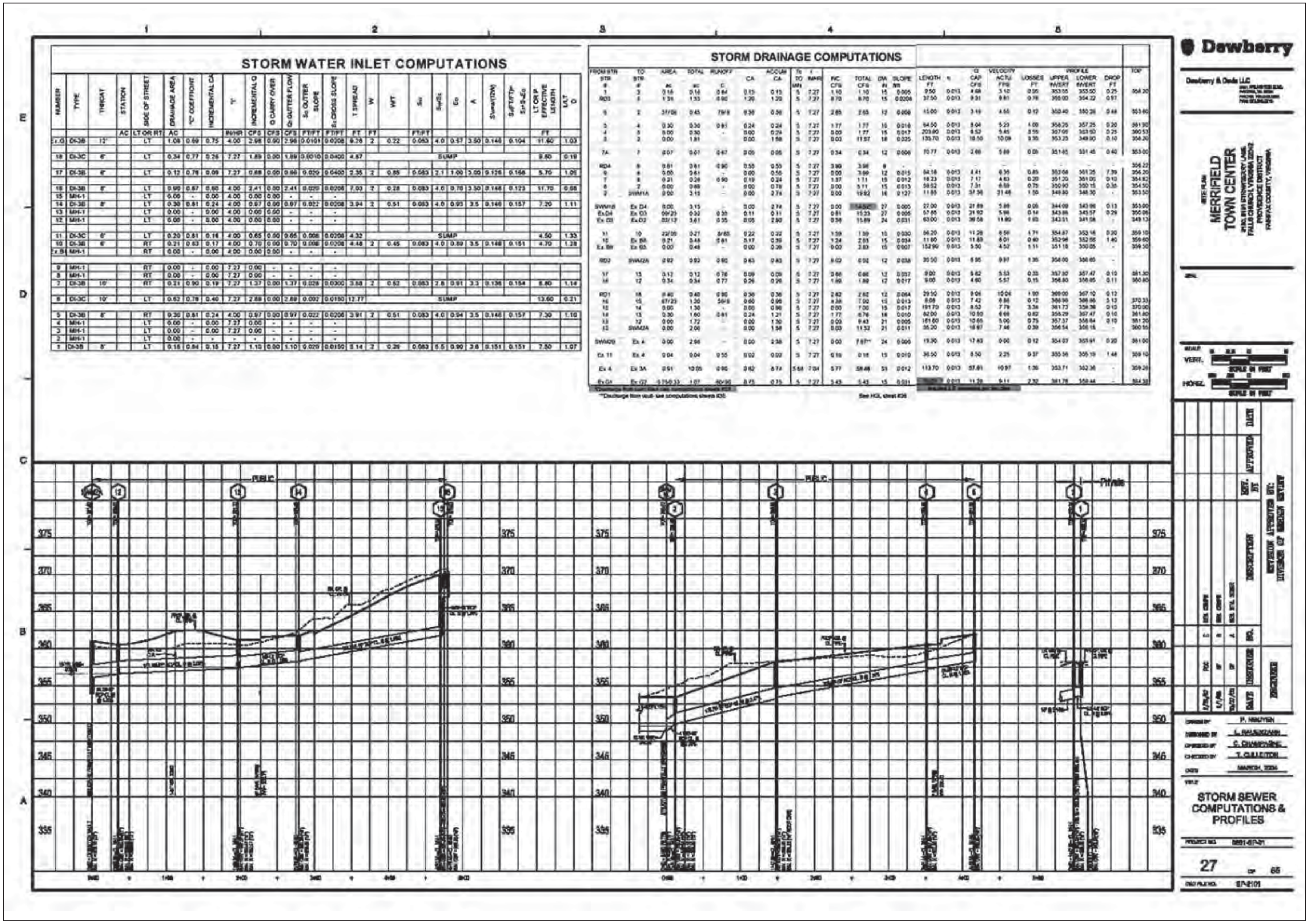


FIGURE 21.21 Storm drain computations and profile.

design, the bypass flow must be included in the runoff discharge for the next downstream inlet.

Pipe Layout

The inlets are then connected to show how the pipes convey the water to the outfall points. The pipe network usually directs the water in the prevailing direction of the slope of the proposed grading. However, there may be some instances where judgment supersedes rule-of-thumb guidelines. Pipe runs of excessive length (e.g., greater than the maximum allowable manhole spacing) require intermittent manholes. Additionally, any changes in horizontal direction or vertical slope of the pipe, (e.g., to go around a foundation or to minimize easements on lots) also require additional manholes. When additional manholes are necessary, the engineer should check whether additional inlets would be beneficial and substitute accordingly. This is not always possible or desirable, but the cost differential between the two is not significant.

Profile the System

Profile this tentative layout on a profile worksheet. Show the existing and proposed grades and mark the locations of the proposed inlets and manholes, as well as the existing (and proposed if available) utility crossings including sanitary sewer, water main, and duct bank crossings. The purpose of this profile is to ensure the pipes have sufficient cover to prevent excessive excavation and to prevent utility crossing conflicts. Utility conflicts need to be identified during the first phase of design so that they do not cause a major redesign of the system in a later design phase. A more accurate profile can be drawn later after the pipe design is complete. This step is highly recommended. Although some construction plans or documents do not require storm sewer profiles, the simple task of putting the design on paper can eliminate countless redesigns of a system and avoid conflicts.

Tentative Pipe Sizes

Estimate the size of each pipe by adding the flows from each inlet above the inlet at the design point. *Recognize that this is not the proper way to calculate flows, as pointed out in the section discussing the rational method.* However, this method, although it overestimates the flow, is adequate to tentatively estimate the pipe size. For small to moderate-sized sites (less than 50 acres) and pipe runs of 800 feet and less, the relative error in the discharge using this method versus the correct method is tolerable for tentatively estimating pipe sizes. Using a hydraulic calculator, or other means, select the smallest pipe size, which conveys the estimated discharge at full flow, at a slope that approximates the ground slope above the pipe. See Chapter 19 for rational method and closed pipe system computation. As the pipes are selected, write this information on the profile worksheet between the appropriate inlets. Draw a line between inlets that represents the invert of the pipe. The crown of the outgoing pipe is set at the same elevation, or higher, than the crown elevation of the lowest incoming pipe. When large junction losses are anticipated, the crown of the incoming pipe should be slightly higher. This increases the difference in elevation in inverts to allow for the large junction losses. Note that these last three statements affect where the invert line of the pipe is drawn.

Final Assessment

Check to see that the invert of the last pipe is above the invert of the outfall point. Confirm all existing and proposed utility crossings. If less-than-minimum clearance is provided where the storm sewer crosses a utility, concrete piers or cradles should be considered to support the storm sewer pipe at the utility crossing. If there are no utility conflicts, proper connections to outfall points are possible, and the engineer is comfortable with the cost effectiveness of the design, perform a more detailed design. That is, correctly compute the discharge through the pipes, fill out the pipe design and hydraulic grade line charts, and accurately draw the profiles. (See Figure 21.21.)

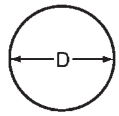
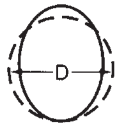
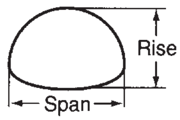
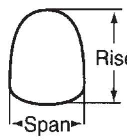
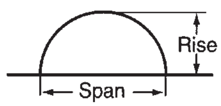
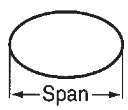
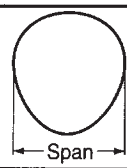
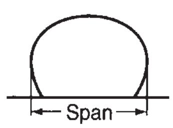
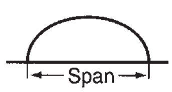
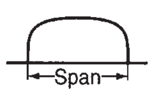
Hydraulic grade line (HGL) computations should be the last step in the design. See prior HGL discussion, this chapter. Although the pipe slopes, if properly designed and set for gravity (nonpressure) flow, head losses through structures and other appurtenances may cause pressure flow in the system. In most cases, where pipe velocities are less than 5 fps, energy losses through manholes are less than 0.5 feet; however, in systems with numerous manholes or in those pipes where velocities are 10 fps and higher, the head losses accrue very quickly. For systems with these characteristics, the potential for pressurizing the system becomes very likely. Even though a specified design storm is used to design the system, local criteria may require that the HGL be checked for other storms. Considerable engineering judgment is required throughout the storm drain design process in assessing the applicable regulations, determining and analyzing a myriad of solutions, and ultimately reviewing the final design to ensure public safety and welfare.

CULVERTS

A culvert is a relatively short length of conduit, typically less than 250 feet long, used to transport water through (or under) an embankment. A culvert, which acts as an enclosed channel through the embankment, serves as a continuation of the open stream. However, flow through culverts depends on entrance geometry and depth of flow at the downstream end. Consequently, flow computations for culverts are more complex than the open channel flow analysis associated with pipes and ditches. Culverts through roadway and railway embankments are designed to pass the design discharge without overtopping the embankment or causing extensive ponding or inundation at the upstream end. Local requirements may allow nominal depths over the embankments for lesser-frequency storm (greater recurrence interval) events.

Components

Major components of a culvert design include specifying the materials—the barrel; end treatments such as headwalls,

Shape		Range of Sizes	Common Uses
Round		6" – 26'	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically-elongated (ellipse) 5% is common		4' – 21' nominal; before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe-arch		Span x Rise 18" x 11" to 20' 7" x 13' 2"	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius, 18 inches or 31 inches for structural plate.
Underpass*		Span x Rise 5' 8" x 5' 9" to 20' 4" x 17' 9"	For pedestrians, livestock or vehicles (structural plate).
Arch		Span x Rise 6' x 1' 9½" to 25' x 12' 6"	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 20' – 40'	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25' – 30'	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20' – 45'	Culverts, grade separations, storm sewers, tunnels, Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20' – 50'	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 3' – 20'	Low-Wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

* For equal area or clearance, the round shape is generally more economical and simpler to assemble.

FIGURE 21.22 Shapes and uses of corrugated conduits.

endwalls, and wingwalls; outlet protection; and inlet improvements such as debris control structures—as well as determining the environmental permitting requirements. Except for the barrel, these components are used as the specific situation warrants.

Barrels are available in various sizes, shapes, and materials. Figure 21.22 shows the commonly used culvert shapes as well as applications of the various shapes. Selection of shape depends on construction limitations, embankment height, environmental issues, hydraulic performance, and cost. The most commonly used culvert materials are corrugated steel, corrugated aluminum, and precast or cast-in-place concrete. Factors such as corrosion, abrasion, and structural strength determine the selection of material. In cases where the culvert is located in a highly visible area, the selection of shape and material may be based on aesthetics as well as the functional aspects.

End treatments, such as headwalls and wingwalls, protect the embankment from erosion, serve as retaining walls to stabilize the bank, and add weight to counter any buoyancy effects. Ideally, the centerline of the culvert should follow the alignment and grade of the natural channel. In many cases this cannot be done, and skewing headwalls and wingwalls helps transition the natural stream alignment to the culvert alignment. Figure 21.23 shows four types of inlet entrances.

Debris barriers are sometimes constructed on the upstream end to prevent material from entering and clogging the culvert. The barriers are placed far enough away from the entrance so that accumulated debris does not clog the entrance.

At the inlet and outlet ends of the culvert, endwalls and wingwalls serve as retaining walls and erosion protection for the embankment and help to inhibit piping along the outside surface of the culvert. Downstream wingwalls provide a smooth transition between the culvert and the natural stream banks.

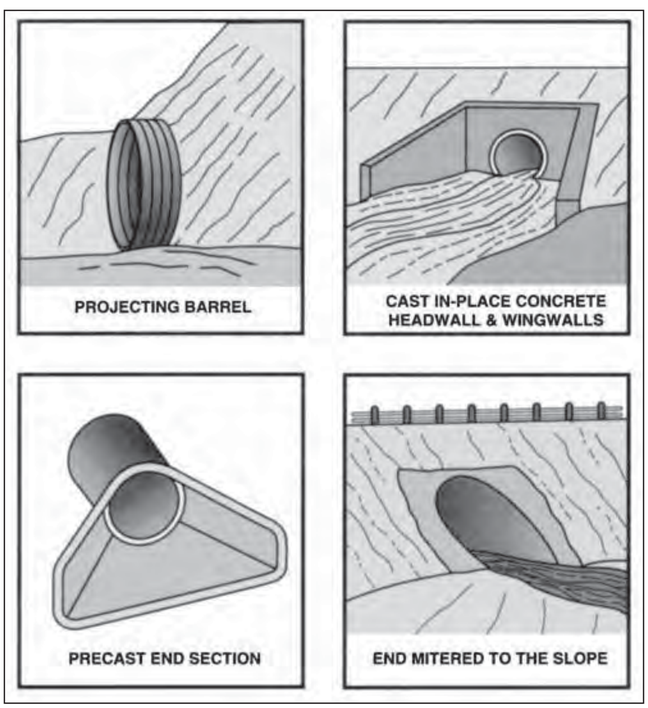


FIGURE 21.23 Four standard end inlet treatments.

All culverts that cross underneath roadway embankments inherently create potential stability concerns for the embankments. The same can be said of storm sewer pipe installations. This is a function of the construction of the culvert system. Compaction around a pipe, whether it is circular or rectangular, is more difficult than standard compaction of fill slopes. The contractor must take care in compacting around culvert systems, usually requiring several "lifts" (e.g., 6- to 12-inch layers of soil) to compact the surrounding fill material to specification. Consideration should always be given, by the designer and the contractor, that storm runoff will seep into roadway embankments or ground water tables will rise during flood events. If the compaction is inadequate, water can run along the voids in the soil of the uncompacted portion of the culvert. When water continues to flow along a pipe or culvert, the uncompacted material slowly washes away from the surrounding pipe, and failure of the embankment may occur. This is one of the most common causes of embankment failures at culvert installations and roadway pavement failures at storm sewer installations. This type of failure is referred to as *piping failure.*

Culverts and storm sewers are typically constructed with a stone base to provide support and flexibility. For most installations, this stone base is porous and allows any water inside the embankment to travel downstream, along the path of the culvert. Typically, this aggregate base aids in reducing piping failures, in that it concentrates the water flowing through the embankment. However, should there be excessive ponding of water behind an embankment, the standard bedding provided at culvert installations will not be adequate to pass the seepage flow safely along the conduit, and piping failures may occur. The designer should consult with a geotechnical engineer to determine appropriate countermeasures, such as concrete cradles, use of impervious materials, or embankment draining devices such as toedrains to minimize the potential for piping failures. Permitting requirements and natural channels require the designer to countersink the culvert 3 to 12 inches, depending on the local, state, and federal laws. The depth of countersinking may be dictated by the type of ground material. Countersinking the culvert provides a natural channel bottom through the culvert for aquatic habitat. The culvert analysis should consider the loss of flow area in the culvert and model the effective opening.

Culvert Hydraulics

In open channel flow, either of three turbulent flow regimes exists: subcritical flow, supercritical flow, or critical flow. The discharge energy, relative to the channel bed, is referred to as the *specific energy* and is mathematically defined as:

$$E = y + \frac{V^2}{2g} \tag{21.44}$$

where y is the depth of flow, V is the average cross-sectional velocity, and E is the specific energy.

For one particular combination of depth and velocity, for a specified discharge, the specific energy is a minimum. This particular discharge is the critical flow. Alternatively, critical flow is the condition of flow when, for a given energy content of the water, the discharge is a maximum. For the same discharge, flows above this minimum energy may exist as either high depth–low velocity or low depth–high velocity. In the former case, flow is subcritical; the latter is supercritical flow. The parameter that distinguishes flow regimes, the *Froude number,* is a dimensionless number. The Froude number, as seen in Equation 21.45, is the ratio of inertial forces to gravitational forces of the flow:

$$F_R = \frac{V}{\sqrt{gd_h}} \tag{21.45}$$

In this equation, d_h is the hydraulic depth (the cross-sectional area of flow divided by the width of the channel at the water surface), V is the velocity, and g is gravitational acceleration. At critical flow $F_R = 1$, for subcritical flow $F_R < 1$, and at supercritical flow $F_R > 1$. The location in the channel section where flow changes from subcritical to supercritical flow—$F_R = 1$—is defined as a control section. At a control section, there exists a unique relation between depth and discharge, given as:

$$Q = \sqrt{g\frac{A^3}{B}} \tag{21.46}$$

where A is the cross-sectional area of flow and B is the width of the channel at the free surface of the water. Hydraulically, a control section restricts the transmission of the effect of changes in flow conditions, either in the upstream or downstream direction, depending on the state of flow.

The amount of water entering a culvert is determined by the location of the control section. If the control section is at the inlet (i.e., inlet control), the amount of flow into the culvert is restricted by entrance conditions and the flow into the culvert is less than what the culvert might actually carry. If the control section is at the downstream end (i.e., outlet control), the amount of flow through the barrel is controlled by the combination of conditions on the downstream side of the culvert, inlet configuration, and hydraulic properties of the barrel itself.

Inlet Control

When the control section is near the inlet, only the headwater depth and inlet configuration determine the amount of water entering the culvert. In most cases, the amount of water entering the culvert is less than what the barrel is capable of carrying. Consequently, the barrel is flowing less than full. Conceivably, for a given inlet configuration, the culvert

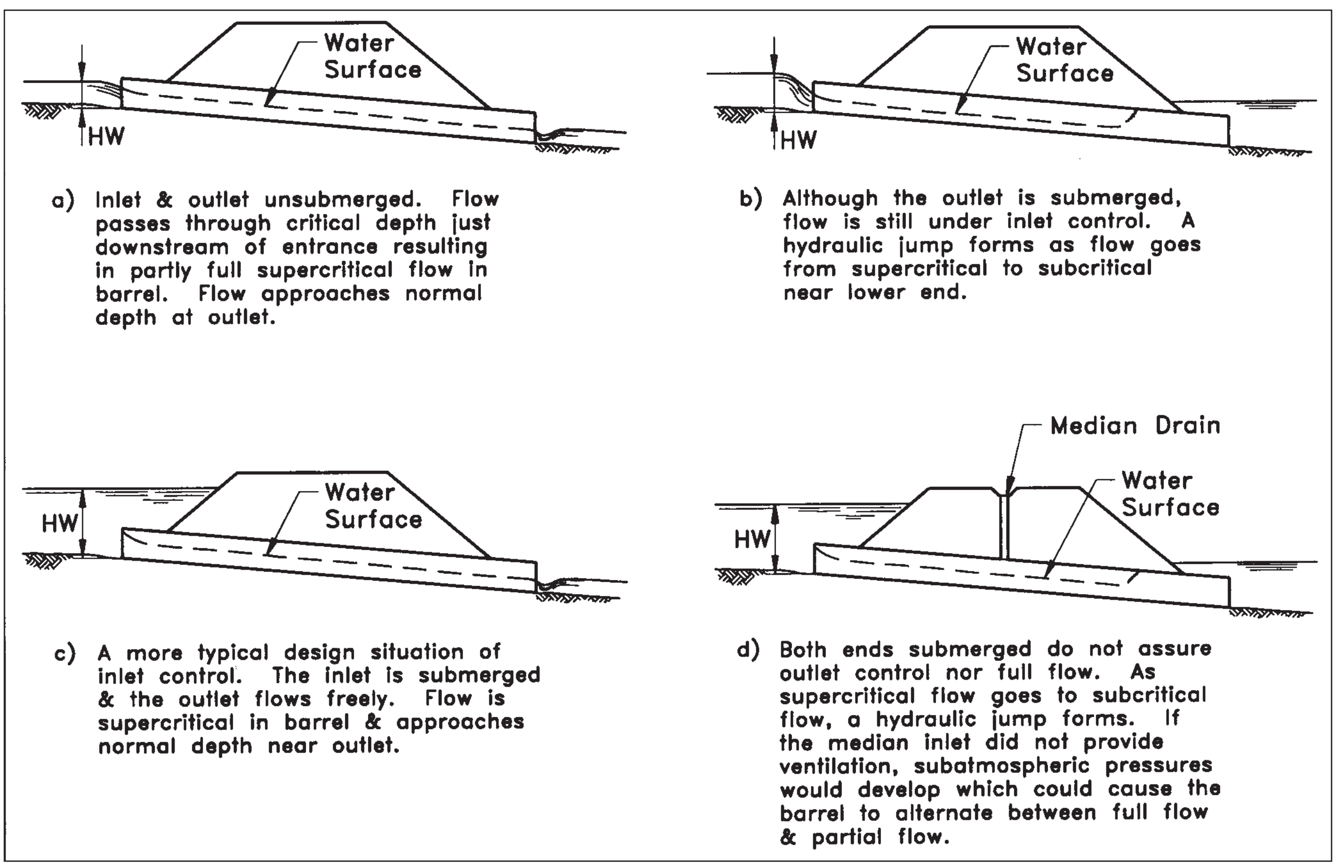


FIGURE 21.24 Types of inlet control.

TABLE 21.7 Constants for Inlet Control Design Equations

				Unsubmerged			Submerged		
Chart No.	Shape and Material	Monograph Scale	Inlet Edge Description	Equation Form	K	M	C	Y	Reference
1	Circular	1	Square edge w/headwall	1	0.0098	2.0	0.0398	0.67	(56) (57)
	concrete	2	Groove end w/head wall		.0078	2.0	.0292	.74	(56) (57)
		3	Groove end projecting		.0045	2.0	.0317	.69	(56) (57)
2	Circular	1	Headwall	1	.0078	2.0	0.379	.69	(56) (57)
	CMP	2	Mitered to slope		.0210	1.33	0.463	.75	(57)
		3	Projecting		.0340	1.50	0.553	.54	(57)
3	Circular	A	Beveled ring, 45° bevels	1	.0018	2.50	.0300	.74	(57)
		B	Beleveled ring, 33.7° bevels		.0018	2.50	.0243	.83	(57)
8	Rectangular	1	30–75% wingwall flares	—	.026	1.0	.0385	.81	(56)
	box	2	90° and 15° wingwall flares	1	.061	.75	.0400	.80	(56)
		3	0° wingwall flares		.061	.75	.0423	.82	(8)
9	Rectangular	1	45° wingwall flare $d = .043D$	2	.510	.667	.0309	.80	(8)
	box	2	18°–33.7° wingwall flare $d = .083D$		.486	.667	.0249	.83	(8)
10	Rectangular	1	90° headwall w/¾· chamfers	2	.515	.667	.0375	.79	(8)
	box	2	90° headwall w/45° bevels		.495	.667	.0314	.82	(8)
		3	90° headwall w/33.7° bevels		.486	.667	.0252	.865	(8)
11	Rectangular	1	¾· chamfers; 45° skewed headwall	2	.522	.667	.0402	.73	(8)
	box	2	¾″ chamfers; 30° skewed headwall		.533	.667	.0425	.705	(8)
		3	¾″ chamfers; 15° skewed headwall		.545	.667	.04505	.68	(8)
		4	45° bevels; 10–45° skewed headwall		.498	.667	.0327	.75	(8)
12	Rectangular	1	45° nonoffset wingwall flares	2	.497	.667	.0339	.803	(8)
	box	2	18.4″ nonoffset wingwall flares		.493	.667	.0361	.806	(8)
	¾″	3	18.4″ nonoffset wingwall flares		.495	.667	.0386	.71	(8)
	chamfers		30° skewed barrel						
13	Rectangular	1	45° wingwall flares, offset	2	.497	.667	.0302	.835	(8)
	box	2	33.7° wingwall flares, offset		.495	.667	.0252	.881	(8)
	Top bevels	3	18.4° wingwall flares, offset		.493	.667	.0227	.887	(8)
16–19	CM boxes	1	90° headwall	1	.0083	2.0	.0379	.69	(57)
		2	Thick wall projecting		.0145	1.75	.0419	.64	(57)
		3	Thin wall projecting		.0340	1.5	.0496	.57	(57)

TABLE 21.7 (*Continued*)

				Unsubmerged			Submerged		
Chart No.	**Shape and Material**	**Monograph Scale**	**Inlet Edge Description**	**Equation Form**	***K***	***M***	***C***	***Y***	**Reference**
29	Horizontal	1	Square edge with headwall	1	0.0100	2.0	0.0398	0.67	(57)
	ellipse	2	Groove end with headwall		.0018	2.5	.0292	.74	(57)
	concrete	3	Groove end projecting		.0045	2.0	.0317	.69	(57)
30	Vertical	1	Square edge with headwall	1	.0100	2.0	.0398	.67	(57)
	ellipse	2	Groove end with headwall		.0018	2.5	.0292	.74	(57)
	concrete	3	Groove end projecting		.0095	2.0	.0317	.69	(57)
34	Pipe arch	1	90° headwall	1	.0083	2.0	.0496	.57	(57)
	18″ corner	2	Mitered to slope		.0300	1.0	.0463	.75	(57)
	Radius CM	3	Projecting		.0340	1.5	.0496	.53	(57)
35	Pipe arch	1	Projecting	1	.0296	1.5	.0487	.55	(56)
	18″ corner	2	No bevels		.0087	2.0	.0361	.66	(56)
	Radius CM	3	33.7° bevels		.0030	2.0	.0264	.75	(56)
36	Pipe arch	1	Projecting	1	.0296	1.5	.0487	.55	(56)
	31″ corner		No bevels		.0087	2.0	.0361	.66	(56)
	Radius CM		33.7° bevels		.0030	2.0	.0264	.75	(56)
40–42	Arch CM	1	90° headwall	1	.0083	2.0	.0379	.69	(57)
		2	Mitered to slope		.0300	2.0	.0463	.75	(57)
		3	Thin wall projecting		.0340	1.5	.0496	.57	(57)
54	Circular	1	Smooth tapered inlet throat	2	.534	.555	.0196	.89	(3)
		2	Rough tapered inlet throat		.519	.64	.0289	.90	(3)
55	Elliptical	1	Tapered inlet, beveled edges	2	.536	.622	.0368	.83	(3)
	Inlet face	2	Tapered inlet, square edges		.5035	.719	.0478	.80	(3)
		3	Tapered inlet, thin edge projecting		.547	.80	.0598	.75	(3)
56	Rectangular	1	Tapered inlet throat	2	.475	.667	.0179	.97	(3)
57	Rectangular	1	Side tapered, less favorable edges	2	.56	.667	.0466	.85	(3)
	concrete	2	Side tapered, more favorable edges		.56	.667	.0378	.87	(3)
58	Rectangular	1	Slope tapered, less favorable edges	2	.50	.667	.0466	.65	(3)
	concrete		Slope tapered, more favorable edges		.50	.667	.0378	.71	(3)

Reference: FHWA, *Hydraulic Design of Highway Culverts,* HDS-5, 1985.

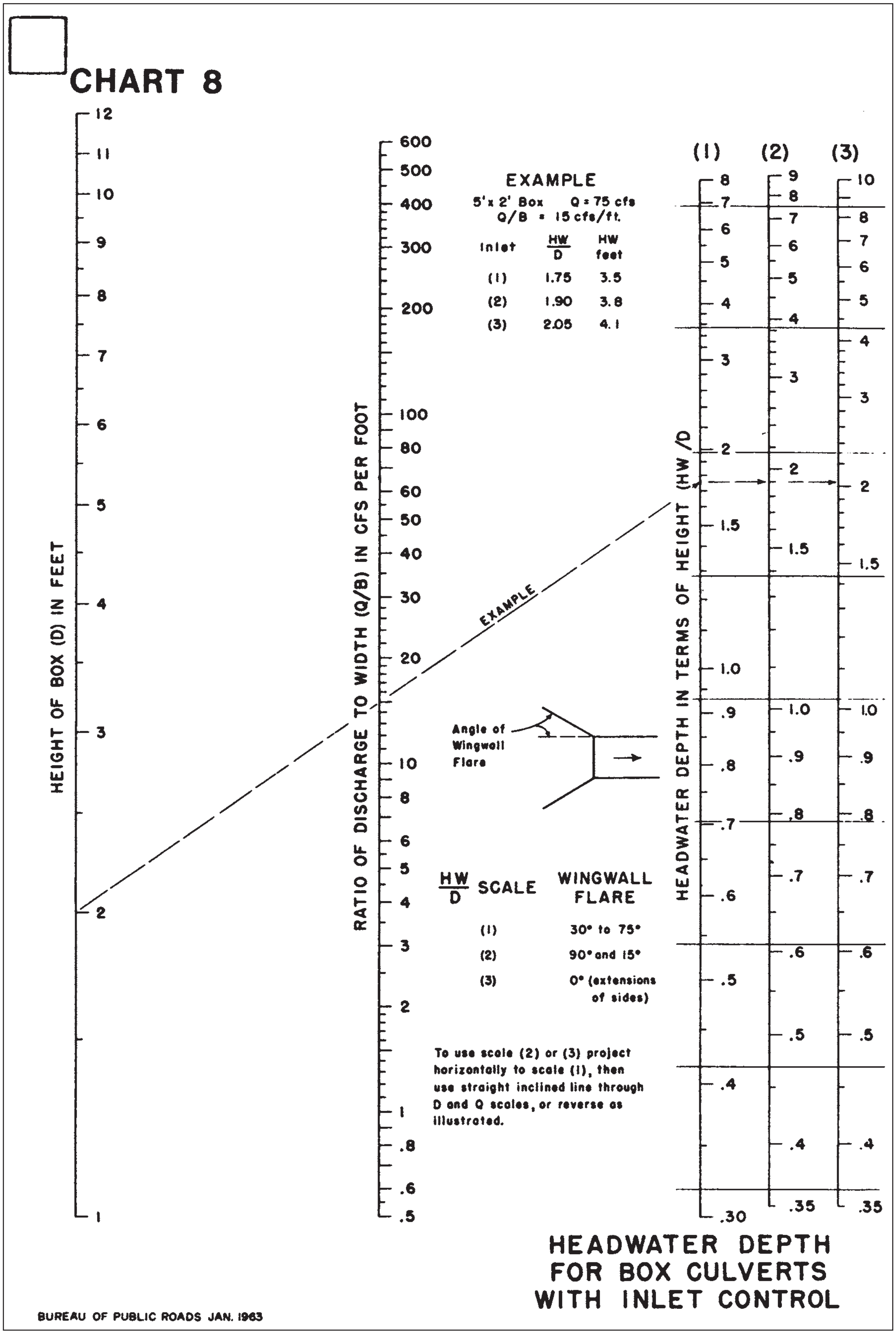


FIGURE 21.25 HDS-5 Chart 8, nomograph for headwater depth for box culvert with inlet control.

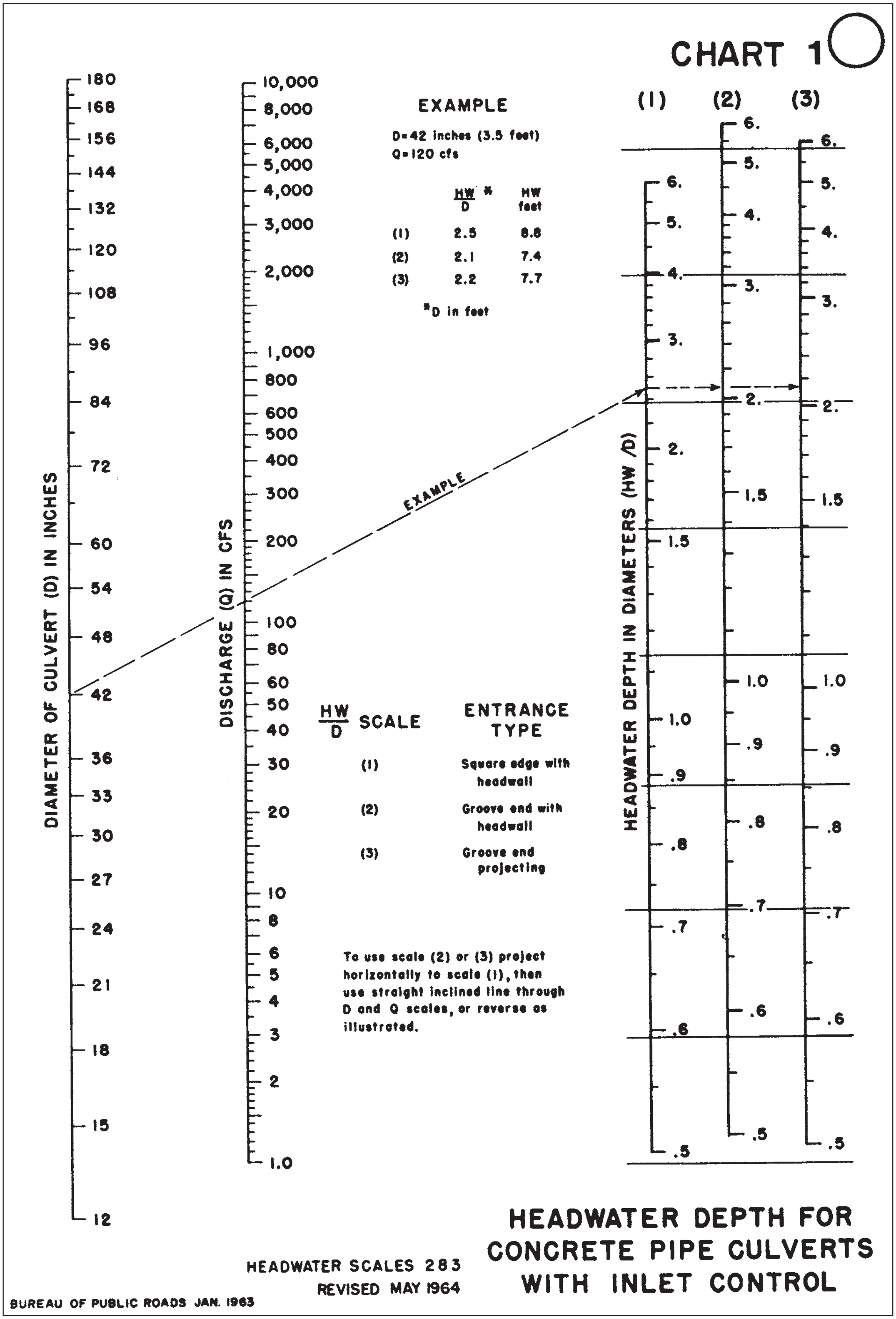


FIGURE 21.26 HDS-5 Chart 1, nomograph for headwater depth for concrete pipe culvert with inlet control.

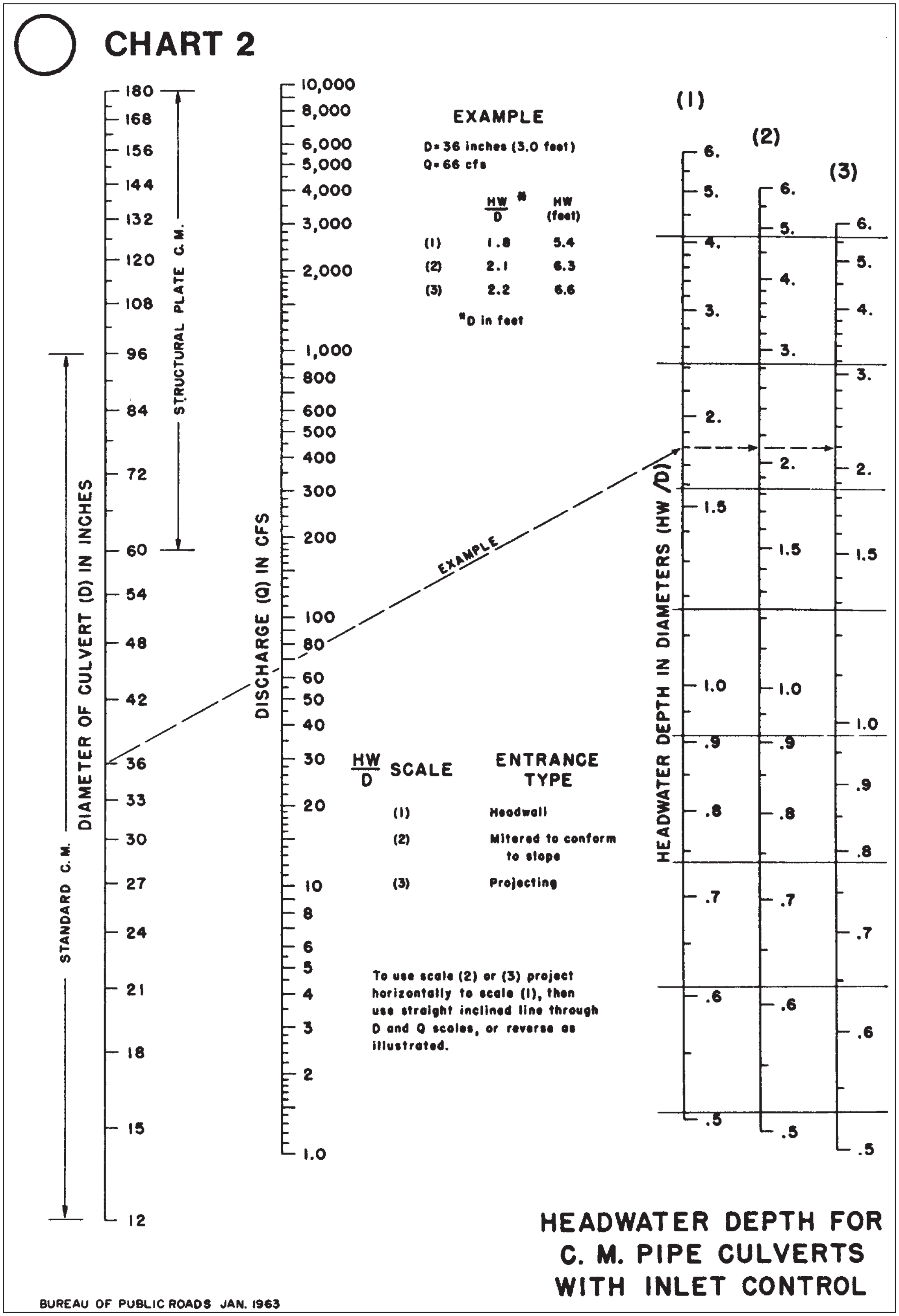


Figure 21.27 HDS-5 Chart 2, nomograph for headwater depth for corrugated metal pipe culvert with inlet control.

can flow full if the headwater depth is high enough to force enough water through the inlet. The headwater depth necessary to achieve full flow in the barrel of the culvert is very large and is usually not achievable, given practical site constraints. Figure 21.24 illustrates the various types of inlet control.

For flows that do not submerge the inlet, as in Figure 21.24*a* and *b*, the flow into the culvert is modeled as weir flow. For submerged conditions, the flow into the culvert is modeled as orifice flow. Equations 21.47, 21.48, and 21.49 were determined from experimental data on culverts by the National Bureau of Standards (NBS). Equations 21.47 and 21.48 are for unsubmerged conditions, and Equation 21.49 is for submerged (orifice) conditions. (Equation 21.48 is another form of Equation 21.47.)

$$\frac{\mathrm{HW}_i}{D} = H_c + K\left[\frac{Q}{AD^{0.5}}\right]^M + C_S \text{ (for } Q/AD^{0.5} \le 3.5) \quad (21.47)$$

$$\frac{\mathrm{HW}_i}{D} = K\left[\frac{Q}{AD^{0.5}}\right]^M \text{ (for } Q/A\,D^{0.5} \le 3.5) \quad (21.48)$$

$$\frac{\mathrm{HW}_i}{D} = c\left[\frac{Q}{AD^{0.5}}\right]^2 + Y + C_S \text{ (for } Q/AD^{0.5} \ge 4.0) \quad (21.49)$$

where HW_i = headwater depth above inlet control section invert (feet), D = interior height of culvert barrel (feet), H_c = specific head at critical depth ($d_c + V^2/2g$) (feet), Q = discharge (cfs), A = full cross-sectional area of culvert barrel (square feet), C_S = slope correction factor (= $0.7S$ for mitered inlets and $C_S = -0.5S$ for all other inlets where S = culvert barrel slope [ft/ft]), and K, M, c, Y = constants from Table 21.7.

The Federal Highway Administration has developed numerous nomographs for various culvert shapes for inlet control. Figures 21.25, 21.26, and 21.27 illustrate several of these nomographs. Others are available in *Hydraulic Design of Highway Culverts* (1985) available through National Technical Information Service, Springfield, VA.

Outlet Control

When the control section is at the downstream side of the culvert, flow through the culvert is either subcritical or pressure flow. Additionally, the amount of flow through the culvert is governed by hydraulic characteristics of both the culvert and tailwater conditions. In culverts under outlet control, the barrel is not capable of carrying all of the water that passes through the inlet. Figure 21.28 shows the various types of outlet control conditions.

Flow through the culvert is a balance between the energy available to pass the water through and the energy consumed by friction and minor losses. The energy balance is given by:

$$\mathrm{HW}_o + \frac{V_u^2}{2g} = \mathrm{TW} + \frac{V_d^2}{2g} + \Sigma H_L \quad (21.50)$$

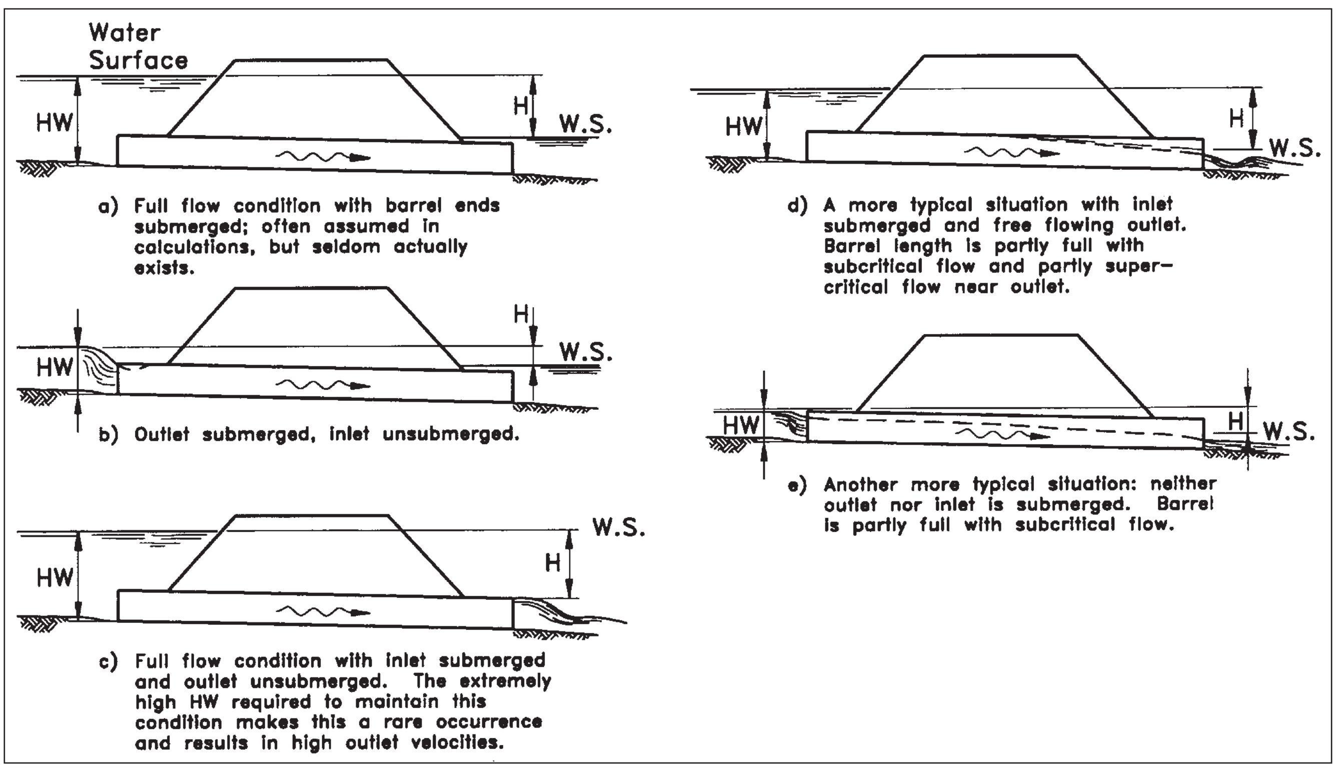


FIGURE 21.28 Types of outlet control.

where HW_o = headwater depth above the outlet invert, V_u = approach velocity of the water at the inlet, TW = tailwater depth above the outlet invert, V_d = discharge velocity of the water at the outlet, and ΣH_L represents the summation of all energy losses through the barrel.

As with pipe flow, energy losses for culverts are attributed to barrel roughness (friction) and minor losses at the inlet and outlet, as well as bends and other appurtenances. Similarly, minor losses are computed as a fraction of the velocity head (kinetic energy) as given in the following equation:

$$h = k\left[\frac{V^2}{2g}\right] \tag{21.51}$$

where the factor k is empirically determined and depends on geometry and hydraulic characteristics. Table 21.8 provides values of k for various entrance conditions. In most cases the k value for exit loss is 1.0.

Friction loss H_f in the barrel of the culvert depends on culvert material and geometry. Using the Manning equation, the friction loss is given as:

TABLE 21.8 Entrance Loss Coefficients

Outlet Control, Full or Partly Full Entrance Head Loss

$$H_e = k_e\left(\frac{V^2}{2g}\right)$$

Type of Structure and Design of Entrance	Coefficient k_e
Pipe, Concrete	
Projecting from fill, socket end (groove end)	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe (groove end)	0.2
Square-edge	0.5
Rounded (radius = 1⁄12 D)	0.2
Mitered to conform to fill slope	0.7
End section conforming to fill slope*	0.5
Beveled edges, 33.7 or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Pipe or Pipe-Arch, Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
End section conforming to fill slope*	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side- or slope-tapered inlet	0.2
Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1⁄12 barrel dimension, or beveled edges on 3 sides	0.2
Wingwalls at 30°–75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1⁄12 barrel dimension, or beveled top edge	0.2
Wingwall at 10°–25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side- or slope-tapered inlet	0.2

**Note:* "End section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both *inlet* and *outlet* control. Some end sections, incorporating a *closed* taper in their design have a superior hydraulic performance.

Reference: FHWA, *Hydraulic Design of Highway Culverts,* HDS-5, 1985.

$$H_f = \left[\frac{29\,n^2 L}{R^{1.33}}\right]\frac{V^2}{2g} \tag{21.52}$$

where n = Manning's roughness coefficient, L = barrel length, and V = average discharge velocity in the barrel. The variable R is the hydraulic radius = A/WP, where A = cross-sectional area of the culvert and WP = wetted perimeter.

The head loss through a straight culvert of uniform cross section is:

$$H = \left(1 + k_e + \frac{29\,n^2 L}{R^{4/3}}\right)\frac{V^2}{2g} \tag{21.53}$$

where k_e is the entrance loss coefficient. For culverts with bends, sudden expansions, and other features that create energy losses, additional terms are added to Equation 21.53.

PROCEDURE FOR CULVERT DESIGN

1. Determine the culvert alignment. The most desirable alignment follows the natural streambed, although factors such as economics, environmental issues, maintenance considerations, and other site constraints contribute to the alignment selection. Setting the alignment also determines the length and slope of the culvert.

2. Select the design storm, which is frequently dictated by state or local criteria. For culverts crossing roadways, the type of roadway affects the design storm. For secondary roads, the recurrence interval may range from 10 to 25 years. On major highways and interstates, the recurrence interval may be 50 years or greater. Other criteria affecting design may be the freeboard distance or depth of flow allowed on the roadway for a storm other than the design storm.

3. Utilizing land use maps, topographic maps, and whatever hydrologic technique is best suited for the area (e.g., rational method, TR-55 methodology, and regional equations), determine the design discharge for the culvert.

4. Select the culvert material and shape that best conform to the constraints of the site. Note that certain materials and shapes may not be readily available from suppliers. For example, low embankment height may warrant the use of elliptical pipe, or high embankments may warrant structurally enhanced material. Aesthetics may also affect the selection of material and shape.

   Size the culvert using either the equations for inlet and outlet control or the culvert nomographs, whichever gives the greatest controlling elevation. The FHWA culvert design form of Figure 21.29 provides a guide to the selection of a culvert. For the design discharge, the headwater depth is computed assuming inlet control and outlet control. The type of control that produces the highest headwater depth is the governing control for the design.

6. After sizing the culvert for the design discharge, check to see that other requirements, as dictated by applicable design standards, are met. Such requirements might include freeboard height or roadway overtopping for lower-recurrence interval storms, effects and impacts of upstream ponding, the need for erosion control for excessive outlet velocities, structural stability, and so on.

Culvert Design Example

Size a concrete (n = 0.013, k_e = 0.5) box culvert for the following constraints: 25-year design discharge = 461 cfs with tailwater depth = 2.6 feet; 100-year design discharge = 690 cfs with tailwater depth = 4.3 feet. At least 1.5 feet of freeboard is required for the 25-year design discharge, and the maximum allowable flow depth over the embankment for the 100-year design discharge is 12 inches. The upstream invert elevation = 314.2 feet, the downstream invert elevation 313.8 feet, and the top of the roadway elevation = 324.5 feet. The culvert is 140 feet long. Assume flared wingwalls with angle of flare between 30° and 75° and square-edge conditions. The minimum allowable cover over the culvert is 3.0 feet. From the given data, the constraints for the 25-year discharge are:

$$\begin{aligned}
&\text{Maximum headwater depth} = 324.5 - 1.5 - 314.2 = 8.8 \text{ ft}\\
&\text{Maximum culvert height} \quad = 324.5 - 3 - 314.2\\
&\qquad\qquad\qquad\qquad\qquad\; = 7.3 \text{ ft}\\
&\text{Slope} \qquad\qquad\qquad\qquad = \frac{314.2 - 313.8}{140} = 0.003 \text{ ft/ft}
\end{aligned} \tag{21.54}$$

Sizing a culvert is a trial-and-error procedure. Estimating a first-try size becomes more intuitive with experience. In this example, select a trial HW/D based on the maximum headwater depth and culvert height, HW/D = 8.8/7.3 = 1.2, to obtain a first approximation. (Note: When finalizing the culvert design, the engineer should consider the physical characteristics of an installation and determine that the culvert will fit safely underneath the roadway pavement box. This should be done by drawing a profile of the culvert with relation to the proposed ground above the culvert. The thickness of the culvert should also be considered when profiling the system.) For inlet control conditions, use the nomograph in Figure 21.25. On the scale at the right, for HW/D = 1.2, extend a straight line to the left scale (height of box) value of 7 and read Q/B = 68 cfs/ft on the middle scale. Therefore, a discharge of 461 cfs requires a 461/68 = 6.8-foot-wide box culvert. The first trial size is 7 feet by 7 feet. The corresponding headwater depth is 8.3 feet.

Now check the HW depth for outlet control conditions. From Table 21.8 for the given headwall/wingwall configuration, the entrance loss coefficient k_e is 0.5. Substituting the values into Equation 21.53 gives:

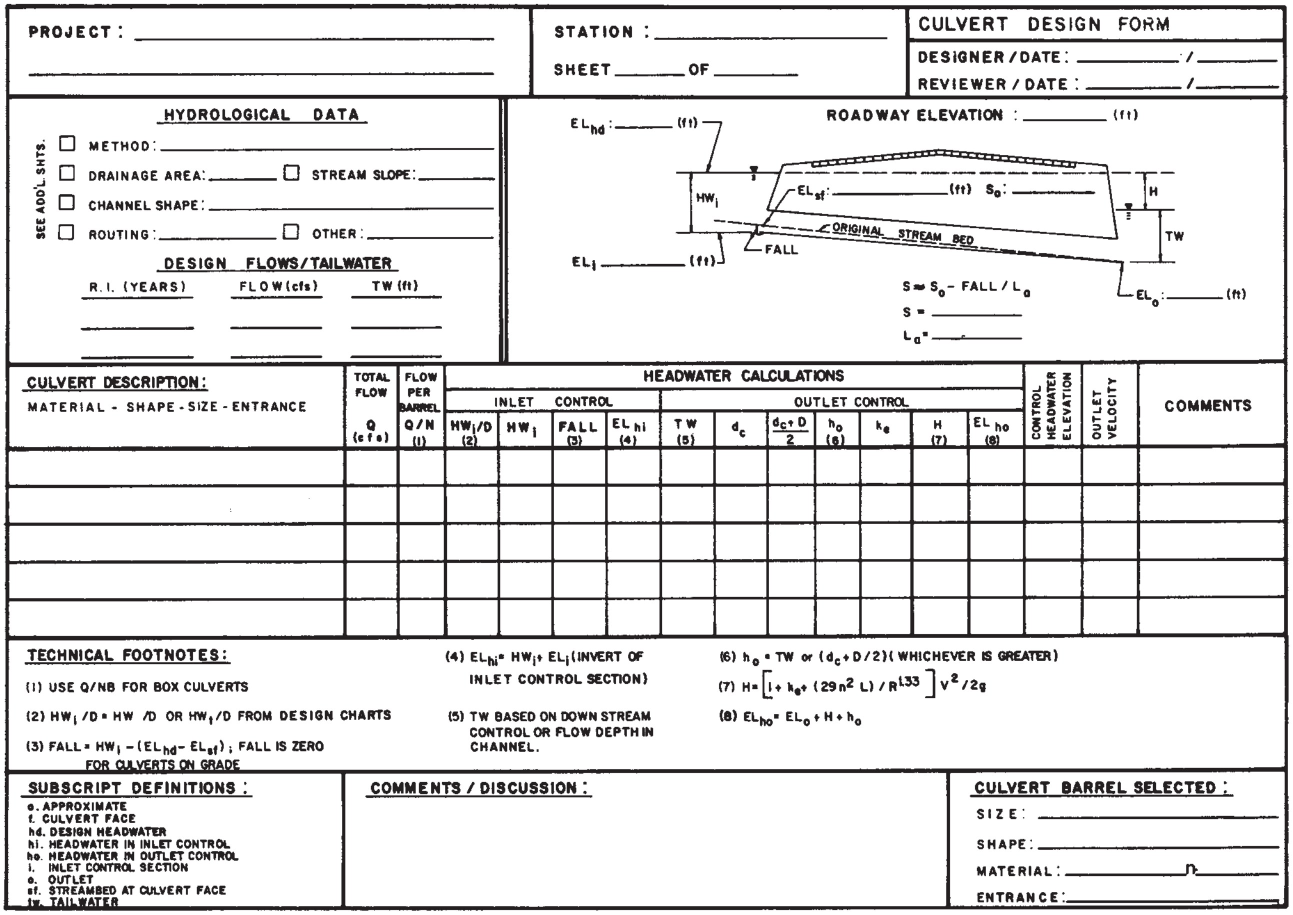


FIGURE 21.29 Culvert design form.

$$H = \left(1 + 0.5 + \frac{(29)(0.013)^2(140)}{(49/28)^{4/3}}\right)\frac{(461/49)^2}{2g} \quad (21.55)$$

$$= 2.5 \text{ ft}$$

The critical depth d_c for the box culvert using the given data is:

$$d_c = 0.315^3\sqrt{\left(\frac{Q}{B}\right)^2} \quad (21.56)$$

$$= 0.315^3\sqrt{\left(\frac{461}{7}\right)^2}$$

$$= 5.1 \text{ ft}$$

and $(d_c + D)/2 = (5.1 + 7)/2 = 6.1$ feet. The variable h_o is the greater of either the tailwater elevation or $(d_c + D)/2$. Here $(d_c + D)/2 = 6.1$ feet > TW = 2.6 feet.

Finally, the headwater depth for outlet control is:

$$\text{HW} = H + h_o - LS_o \quad (21.57)$$

$$= 2.5 + 6.1 - 140\ (.003) = 8.1 \text{ ft}$$

Since the headwater depths for both inlet control (= 8.3 feet) and outlet control (= 8.1 feet) are less than or equal to the maximum allowable headwater depth (= 8.8 feet), a 7-foot by 7-foot box culvert is an acceptable size. Also, since the headwater depth for inlet control is greater than the headwater depth for outlet control, the culvert operates as inlet control.

The second part of the design is to check whether the flow depth over the road embankment for the 100-year discharge is less than 12 inches. From the nomograph in Figure 21.25, extend a straight line from the left scale (height of box = 7 feet) through the $Q/B = 690/7 = 98$ cfs/ft and read HW/D = 1.8 on scale 1 at the left. The resulting headwater depth = (7 × 1.8) = 12.6 feet.

Now determine the headwater depth for outlet control conditions. From Equation 21.53:

$$H = \left(1 + 0.5 + \frac{(29)(0.013)^2(140)}{(49/28)^{4/3}}\right)\frac{(690/49)^2}{2g} \quad (21.58)$$

$$= 5.6 \text{ ft}$$

This same value can be obtained using the outlet control nomograph for the concrete box culvert of Figure 21.30. First, draw a straight line from the dimension of square box scale (7 feet by 7 feet) to the length scale value of 140 feet for $k_e = 0.5$. Next, draw a straight line from the discharge scale

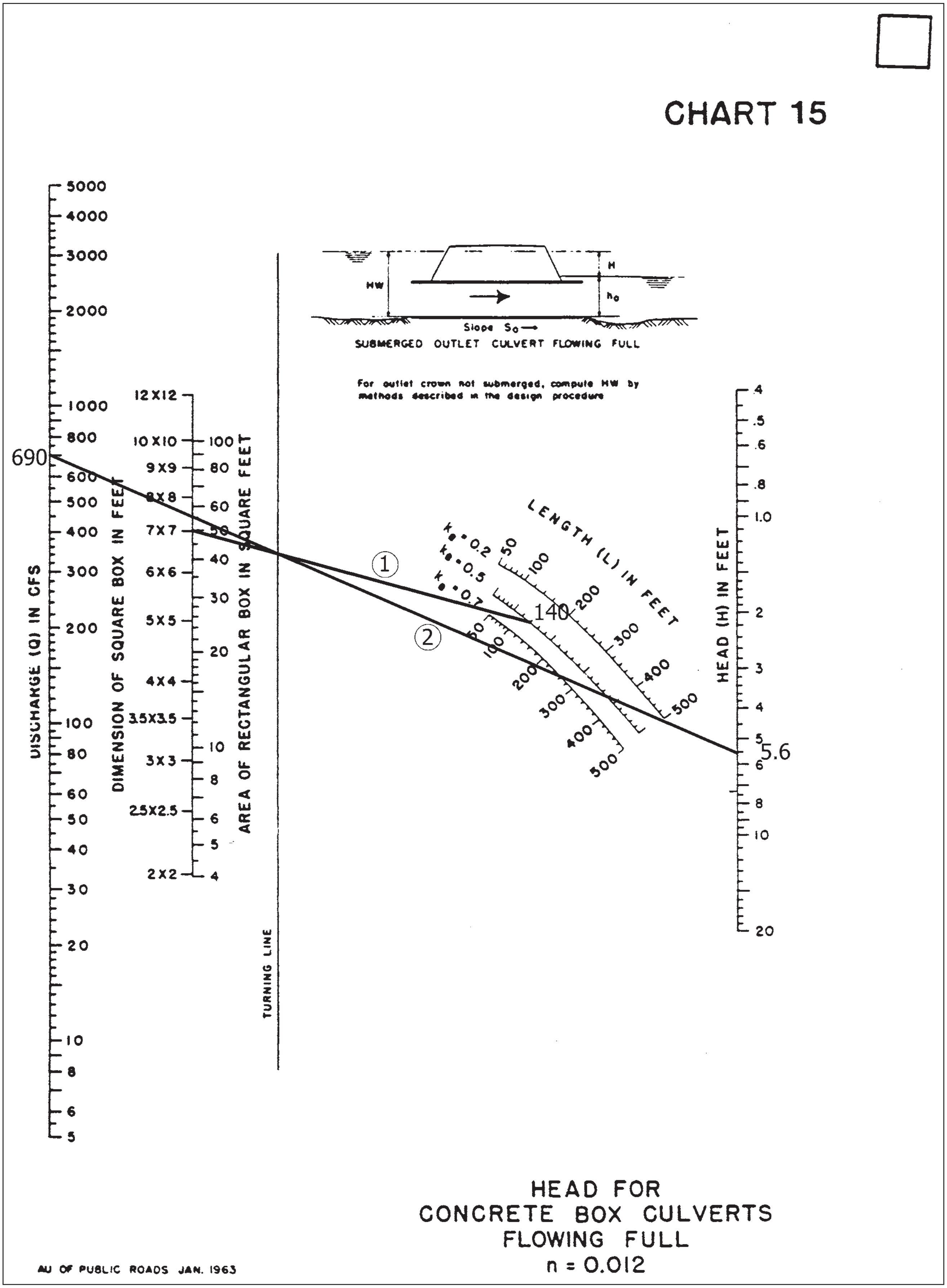


FIGURE 21.30 Outlet control nomograph for example problem.

(= 690 cfs) through the point where the previously drawn line intersects the turn line to the head (H) scale on the left. Read a value of $H = 5.6$ feet.

The critical depth d_c is:

$$d_c = 0.315 \sqrt[3]{\left(\frac{Q}{B}\right)^2} \tag{21.59}$$

$$= 0.315 \sqrt[3]{\left(\frac{690}{7}\right)^2}$$

$$= 6.5 \text{ ft}$$

where $(d_c + D)/2 = (6.5 + 7)/2 = 6.8$ feet. Hence, the variable $h_o = 6.8$ feet. The headwater depth for outlet control is:

$$\text{HW} = H + h_o - LS_o \tag{21.60}$$

$$= 5.6 + 6.8 - 140\,(.003) = 12.0 \text{ ft}$$

For the 100-year discharge, the culvert operates under inlet control (i.e., 12.6 > 12.0).

Based on the assumption of no roadway overtopping, the headwater elevation for the 100-year discharge is 326.8, which is 2.3 feet above the road. Finding the actual depth over the road is another trial-and-error procedure. For a given headwater (above elevation 324.5 feet), the total flow is the amount that the given headwater depth pushes through the culvert plus the amount of flow going over the embankment. The objective is to find the headwater depth where the combined flows equal the specific design discharge.

Flow over the embankment is typically modeled as a weir. The length of the weir and depth of water over the weir are difficult to determine when the road profile is a sag vertical curve or when the embankment surface has a very irregular shape. There are various numerical methods to approximate each of these values. Sometimes a simple approximation of a broad crested rectangular weir can be used. For more complex situations, many culvert analysis programs allow for the input of the roadway profile above the culvert and calculate the weir flow incrementally over the road until the resulting discharge balances. Weir flow is:

$$Q_w = C_w L\, H^{3/2} \tag{21.61}$$

where C_w is a weir coefficient that depends on the shape and depth of water above the weir relative to the depth of water below the weir, L is the length of the weir, and H is the depth of water above the weir. For a broad crested trapezoidal weir, C_w ranges between 2.5 and 3.1. Refer to hydraulic handbooks, such as Brater et al. (1996), for various other values for different types of weirs.

To determine whether the roadway overtops less than 1 foot, as was required in the example problem, we will assume that a 50-foot-long rectangular weir approximates the overtopping portion of the roadway. Using Equation 21.61, a $C_w = 2.6$, $L = 50$ feet, and $H = 1$ foot (allowable overtopping) yields a weir discharge of 130 cfs. Next, we determine whether the combination of weir flow and culvert flow, at the allowable elevation of 325.5 feet (1 foot above the road elevation), is sufficient to pass the 100-year discharge.

Using an elevation of 325.5 feet, the corresponding HW/D ratio is (325.5 − 314.2)/7 = 1.61. From the box culvert with inlet control nomograph (Figure 21.24), construct a straight line from HW/D scale (1) at HW/D = 1.61 to the left scale for $D = 7$ feet. Read $Q/B = 90$ and find $Q = 7(90) = 630$ cfs. The total flow of culvert and weir flow is 630 + 270 = 760 cfs. Our 100-year design discharge is equal to 690 cfs. Therefore, there is sufficient capacity within the culvert and the 1 foot of allowable overtopping of the road to pass the design discharge. A trial-and-error process using the same procedures could calculate the actual 100-year water surface elevation.

This example uses the culvert nomograph for inlet control to calculate the headwater depth. Equations 21.47, 21.48, and 21.49 could also have been used for the same purpose. The nomograph is convenient and quick, however, and the equations can be incorporated into computer programs or hand-held calculators. A variety of computer programs are available to assist and automate the culvert analysis process. There are also numerous inlet and outlet nomographs for various culvert shapes that can be found in *Hydraulic Design of Highway Culverts* by the FHWA, available from National Technical Information Service (NTIS), Springfield, Virginia.

Major Culverts

The preceding example demonstrates how a 7-foot by 7-foot box culvert would meet the minimum design requirements for the given discharges. Major culverts usually have different definitions in different localities but are usually large single- and multiple-cell culverts with drainage areas of 200 acres or greater. These crossings may not fall under floodplain requirements mandated by localities or the federal government; therefore, careful consideration should be given to the analysis, design, and construction of these structures.

When analyzing larger culvert crossings, simple single-basin hydrology or rational method hydrology may not be appropriate. Developing models to take into account terrain, soil types, land covers, and various inflow points may be necessary; therefore, developing a rainfall runoff model such as HEC-HMS or TR-20 may be appropriate. Regression equations or other regionally adopted approaches may be suitable and even required by some localities to estimate the runoff to the culvert. The range of storms required for analysis may vary as well. Larger culverts may need to be designed for 25-, 50-, or even the 100-year storm events based on the classification of the roadway, proximity to existing or proposed development, or localized soil conditions.

Hydraulic analysis and design of these major culvert crossings may also require more complex approaches than previously described. The nomographs used in the previous example, although still effective in predicting the appropriate size of a culvert, may be overly conservative. With many major culvert crossings, a more appropriate hydraulic analysis may be more similar to a stormwater management or reservoir routing process than simple pipe flow. The nomograph approach does not consider storage on the upstream side of the culvert. Hand calculations (typical reservoir routing) or most simple hydrologic computer programs can handle these calculations, and the results give a more realistic answer to the headwater elevations and discharge through the culvert. The computer models can also give you an approximation of the amount of time the culvert embankments may be saturated during a particular storm event. Oversaturation of water sitting behind a culvert for long periods of time could cause eventual slope and/or erosion problems with certain soil types and embankments.

More detailed hydraulic programs (step backwater programs such as HECRAS or WSPRO) may also be helpful in analyzing the impacts major culverts have on the upstream property. Major culverts may also have bend losses or be located in series such that these models can better predict the water surface elevations for the different design storms. Upstream conditions may be more affected by the headwater conditions at the culvert, and as a result, you can more accurately determine the amount of impact to the upstream property and where that impact would dissipate or tie out. This type of analysis may be required (even if a floodplain analysis is not) so that the proper easements can be obtained upstream to encompass the predicted increase in water surface elevations.

There are other issues when dealing with major culverts that may factor into the overall size and hydraulic requirements. For instance, upstream flood stages may be increased above what might be acceptable. Besides the local design criteria, another consideration is the amount of upstream land inundated because of the increased flood elevation. In flat areas, with significant land value, a 0.5-foot rise in flood stage may mean acres of land impacted by flooding, resulting in reduced development potential or increased development costs for grading. Therefore, the cost to increase the culvert size in order to reduce upstream water surface elevations could be warranted.

Another consideration to culvert sizing includes providing for the increase in runoff from proposed upstream development. Oftentimes, communities require that the designer consider the potential for upstream development, usually based from an approved comprehensive or zoning plan. For many culvert installations, the required design storm could be the 10-, 25-, or even 50-year storm. Most localities do not regulate SWM controls to mitigate for the 25- or 50-year storm events. Many localities only consider the 10-year and smaller events. Therefore, a culvert located in the lower part of a watershed, especially where development potential is high, should be sized to accommodate the increase in peak discharges over time.

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CHAPTER 22

STORMWATER MANAGEMENT DESIGN

P. Christopher Champagne, PE

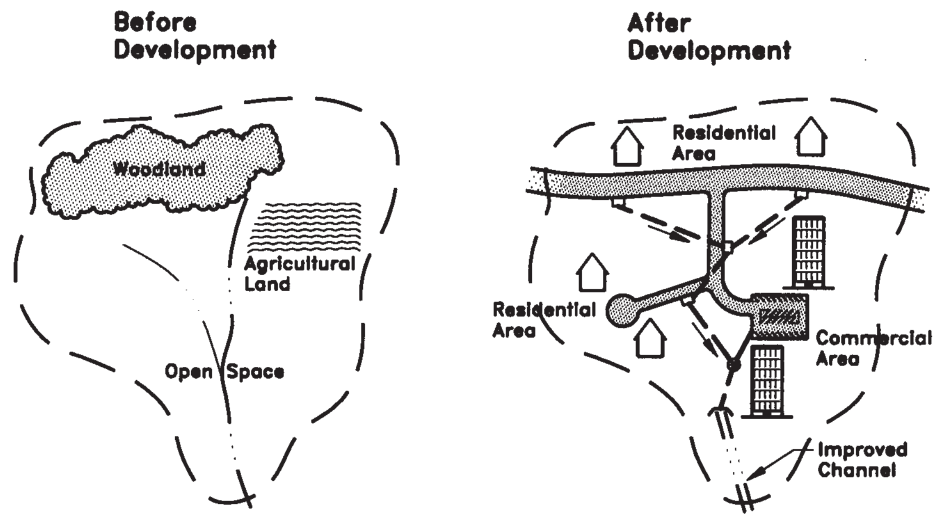
INTRODUCTION

Transforming land from vacant or rural to residential/commercial use inevitably results in a decrease in pervious surface and an increase in impervious surface. This transformation in the surface results in a change in the hydrologic and hydraulic characteristics of the watershed. The development of watersheds has historically resulted in an increase in the postdevelopment flow rates, the runoff volumes, and frequency of flooding as well as the degradation of surface water quality. In order to convey the increased runoff, systems consisting of curb and gutter, storm sewer, paved or earthen ditches, and channels are typically developed to safely convey the runoff through the developed basin. These man-made conveyance systems directly increase flow velocity, which decreases the basin time of concentration, resulting in higher peak flow rates. This increase can be fairly dramatic when you consider that in a typical moderately developed watershed, the increase in peak discharge could be from two to five times higher than predeveloped conditions. Perhaps more important, the volume of runoff can be increased by as much as 50 percent and the time of concentration may be decreased by an even greater percentage (see Figure 22.1).

Along with the increase in water quantity, urbanization results in an increase in non-point-source (NPS) pollutants. Trace metals from galvanized downspouts, flashing and roofing materials, and pipes are washed into natural channels. Other pollutants such as tire particulate, hydrocarbon products from pavement and fuels, and mechanical part flakes can all end up in the surrounding streams, lakes, and ground water. The damaging effects of the many pollutants are not always immediately apparent. It may be years before fish and wildlife are affected by land use changes or before these effects become noticed. Damaging effects from other pollutants such as phosphorus and nitrogen, when washed into lakes, promote algae growth. If left unchecked, eutrophication and water quality degradation are imminent.

Stormwater management (SWM) is the mechanism for controlling stormwater runoff for the purposes of reducing downstream erosion and flooding and mitigating the negative effects resulting from urbanization. Many localities have ordinances that require specific action to mitigate such potential damage. Within the broad scope of the Clean Water Act, local authorities are compelled to implement measures such as sediment and erosion control and stormwater quantity and quality controls, often called best management practices (BMPs), to diminish the negative effects of land use changes. Best management practices are those techniques used to control NPS pollution. As discussed in previous chapters, local jurisdictions may have additional SWM performance requirements, commonly ground water recharge, which can greatly affect the overall site SWM strategy. While classic SWM techniques centered on the detention/retention[1] of stormwater runoff, modern techniques look to decrease not only the peak runoff rate, but also the total volume of runoff. In order to manage runoff rate *and* volume, these techniques utilize infiltration and/or collect rainwater for reuse in order to replicate the predevelopment hydrologic conditions of the site.

[1]To clarify, in this chapter a detention pond is a dry pond, one that holds water for a short duration (i.e., less than 72 hours) after a storm event. After the water is released, the detention pond remains dry until the next storm. A retention pond has a permanent pool of water.



Watershed Parameters	Before	After
Area	100 Acres	100 Acres
Avg. Slope	2%	2%
Land Use	Open Space/Agriculture	Mixed Use: Med. Density Res. & Light Comm.
Soils	Moderate Infiltration (Hydrologic Soil Group B)	Moderate Infiltration (Hydrologic Soil Group B)
% Imperviousness	15%	60%
Rational Runoff C-Coefficient	0.10	0.5
Time of Concentration	50 Minutes	15 Minutes
Peak Discharge 2 Yr Storm	16 cfs	80 cfs
Peak Discharge 10 Yr Storm	23 cfs	125 cfs

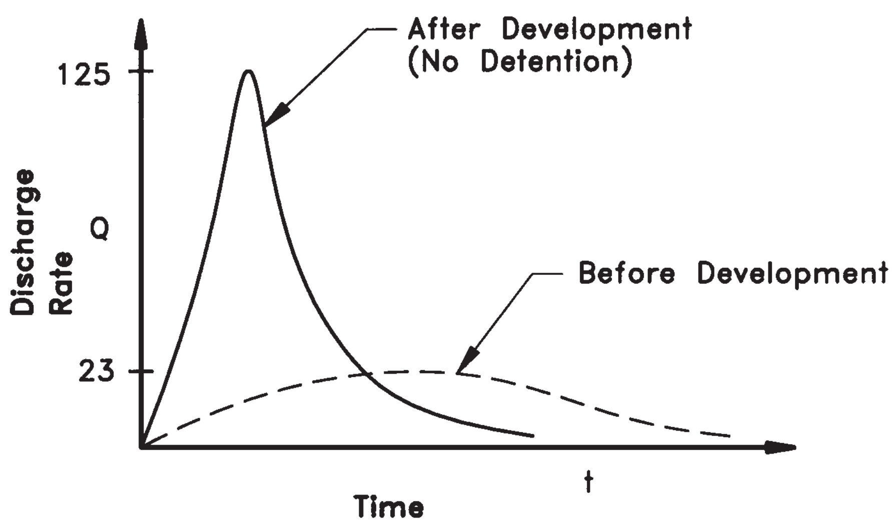


FIGURE 22.1 Hydraulic and hydrologic effects of urbanization.

The modern approach to SWM often involves a combination of facilities and technologies in order to address the various performance requirements in a given jurisdiction as well as accommodate the unique opportunities and constraints presented on a project/site. This chapter discusses the basic concepts for hydraulic analysis, design techniques for sizing and locating various SWM facilities, and various types of best management practices that can be incorporated into the land development program.

FUNDAMENTALS OF STORMWATER MANAGEMENT

Moving forward, it is important to utilize a common terminology. To that end, a glossary of the critical terms used in this chapter follows.

Stormwater Management (SWM): A combination of natural and technological site features that address the quantity and quality of stormwater runoff from a site.

Quantity Control: This term is used to describe the need to reduce peak rate of runoff from a site. Increasingly today, it describes a desire to reduce the peak rate of runoff from a site back to existing or predevelopment rates but also to reduce the total volume of runoff from a site back to predevelopment amounts.

Quality Control: This term is used to describe the practice by which the sediment within the runoff from the site is captured. A common measure of the effectiveness of quality control is total suspended solids (TSS) removal. However, it should be noted that various jurisdictions (depending on local concerns) may want to capture a specific pollutant and not just the TSS. Specific pollutants of interest include nutrients such as phosphorus and nitrogen.

Ground Water Recharge: This term is used to describe the benefits of infiltrating stormwater runoff back into the water table.

Hydrology: The study of precipitation and the movement of water throughout the water cycle. See Chapter 19 for further details.

Hydraulics: The study of the flow of water through hydraulic structures including orifices, weirs, pipes, and culverts.

Stage-Storage: A graphical representation of the relationship between the depth of water and the associated storage volume in an SWM facility, or H versus V (*x:y*). In natural facilities such as ponds, the graph is a curve; in manufactured systems such as vaults, the graph is a straight line. Volume may be computed using any standardized volume formula; average end-area and conic approximation methods are common (see Chapter 23 for additional guidance on earthwork or volume computation methodologies).

Stage-Discharge: A graphical relationship between the depth of water in the SWM facility and the discharge or outflow from the facility, or H versus Q (*x:y*).

Best Management Practices (BMPs): A series of structural and nonstructural techniques employed to improve the water quality of runoff from a developed site.

Integrated Management Practices (IMPs): Small, decentralized, "at the source" techniques used to minimize the effects of development on the hydrologic cycle.

LEED-NC SS Credit 6.1 Stormwater Quantity: There are two options for credit compliance based on the existing site impervious condition. If the site is 50 percent impervious or less, the postdevelopment peak rate *and* volume should not exceed the predevelopment levels for the 1- and 2-year, 24-hour design storm. If the site is more than 50 percent impervious, the postdevelopment volume of runoff should reflect a 25 percent reduction from the existing condition volume for the 2-year, 24-hour design storm.

LEED-NC SS Credit 6.2 Stormwater Quality: BMPs capable of providing 80 percent total suspended solids (TSS) removal (based on field performance data) shall be provided to capture and treat 90 percent of the average annual rainfall. Ninety percent of the average annual rainfall is equivalent to 1 inch, 0.75 inch, or 0.50 inch, depending on whether the site is located in a humid, semiarid, or arid climate.

PRINCIPLES OF HYDROLOGIC ROUTING

When thinking about the design of any stormwater management detention facility it is important to understand that the critical volume of storage needed to detain the flow back to a certain release rate is based on a simple premise: as flow enters the facility (inflow *I*) it needs to be either stored (storage *S*) or released (outflow *O*).

More specifically, as a flood wave passes through a storage facility it is both delayed (time) and attenuated (peak) as it spreads over the pool surface. The amount of attenuation depends on the stage-storage characteristics of the facility *and* the stage-discharge characteristics of the outflow structure. The amount of attenuation and delay is reflected in the shape of the outflow hydrograph and the position of the peak outflow. Perhaps the most widely used method of reservoir routing, where the relationship between the rate of outflow and the amount of storage is nonlinear, is the storage indication method also known as the *modified Puls method.*

To employ this method, the known parameters must include: (1) inflow hydrograph, (2) stage-storage relationship, and (3) stage-discharge relationship.

Underlying assumptions behind this routing method are that the reservoir water surface is always level and that the outflow from the facility is a unique function of storage. The procedure is based on the repetitive application of the conservation of mass equation. The difference between the inflow I and the outflow O during an incremental element of time, Δt, is the change in storage ΔS. This continuity principal is mathematically expressed as:

$$I - O = \frac{\Delta S}{\Delta t} \tag{22.1}$$

With reference to Figure 22.2, the equation in discretized format, where the subscripts n and $(n + 1)$ represent the values at the beginning and ending points of the Δt increment, is:

$$\left(\frac{I_n + I_{n+1}}{2} - \frac{O_n + O_{n+1}}{2}\right)\Delta t = S_{n+1} - S_n \tag{22.2}$$

Rearranging terms to get the known quantities on the left side of the equality gives:

$$(I_n + I_{n+1}) + \left(\frac{2S_n}{\Delta t} - O_n\right) = \frac{2S_{n+1}}{\Delta t} + O_{n+1} \tag{22.3}$$

where I = inflow, O = outflow, S = storage, and t = time, and the right side of the equation is the storage indication variable. The increment of Δt is selected such that the hydrograph shape between the values of I_n and I_{n+1} and O_n and O_{n+1} is approximately linear. The graphical representation of this equation is shown in Figure 22.2. In the calculation process, the stage-storage and stage-discharge relationships are used to develop a storage-indication discharge relationship; this curve is then used to find the value of O_{n+1}.

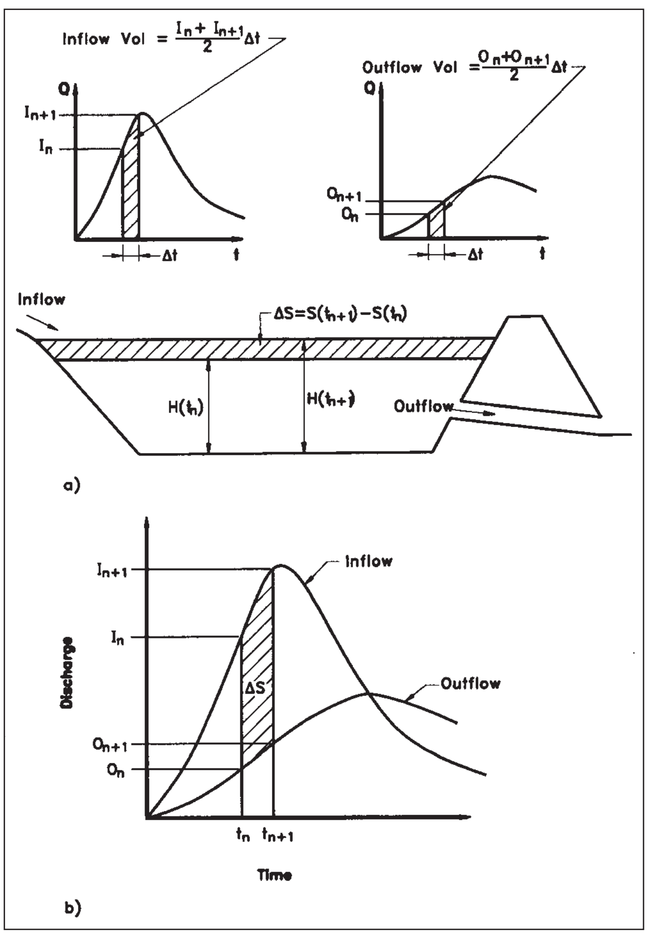


FIGURE 22.2 Storage change (*a*) in a reservoir, (*b*) from inflow-outflow hydrographs. (Courtesy of Haan, C.T., and B.J. Barfield. *Hydrology and Sedimentology of Surface Mixed Lands.* Copyright © 1978 by the Office of Continuing Education and Extension, College of Engineering, University of Kentucky, Lexington, Kentucky, 40506)

PRINCIPLES OF HYDRAULIC DESIGN

A stormwater management facility usually consists of an impoundment area, a principal spillway structure, and an emergency spillway. The impoundment area may be a natural depression, a dam embankment, a completely excavated impoundment, a structural (constructed facility such as a vault with a clearwell), or some combination thereof. The principal spillway usually consists of an outlet conduit through the embankment or from the clearwell, draining to the outfall channel. Often, the principal spillway incorporates a control structure frequently referred to as a *riser* structure, with a combination of orifice openings and weirs to regulate the amount of flow passing through it. The emergency spillway may be a channel cut around/through a portion of the dam embankment or an overflow mechanism built into the clearwell.

The design of these control structures is based on the fundamentals of hydraulics. For the spillway configuration, a stage-discharge relationship, that is, a rating curve, is developed. To develop the rating curve, one must understand how water flows over weirs and through orifices and culverts.

Discharge through an orifice is given by:

$$Q = C \times A \times \sqrt{2 \times g \times H} \tag{22.4}$$

where C = a coefficient, typically = 0.6; A = area of orifice opening (ft^2); g = gravitational acceleration = 32.2 ft/s^2; and H = height of water (ft) in the pond above the centroid of the orifice, or the difference in water surface elevations on the upstream and downstream sides of the orifice.

Discharge over a weir is computed as:

$$Q = C \times L \times H^{1.5} \tag{22.5}$$

where C = a weir coefficient, usually C = 2.5 to 3.3; L = weir crest length (ft); and H = height (ft) of water above weir crest.

If the weir is submerged (water elevation on the downstream side of the weir is above the weir crest), the effect of submergence on the computed discharges should be checked. Values of the orifice and weir coefficients and the effects of submergence on weirs can be obtained from hydraulics manuals such as Brater and King (1976).

For flow through a conduit pipe or open channel, use Manning's equation; for a culvert, use the equations and nomographs from *Hydraulic Design of Highway Culverts,* Hydraulic Design Series No. 5 (HDS-5) by the Federal Highway Administration (FHWA), or the electronic version HY-8 can be used. HDS-5 provides methods for analyzing and designing pipes of all different sizes, shapes, and materials, to determine the energy or head loss associated with a given discharge for both inlet and outlet control conditions. (See Chapter 21 for procedures on culvert design.)

A drop inlet spillway should be designed so that full flow is established through the culvert and riser at as low a head over the riser crest as practical and before the head over the top of the riser becomes so large that the riser begins to act as an orifice instead of a weir. If the top of the riser acts as an orifice, and the riser and outlet pipe are flowing partly full, surging and vibration can occur. This unstable situation can result in damage to the spillway, as well as excessive noise during operation. To prevent this, the riser should have a larger cross-sectional area than the outlet pipe. To determine whether the top of the riser is flowing as a weir or an orifice, the discharge is computed for a given water surface elevation using both the orifice equation and the weir equation. The equation that gives the lesser amount of flow is the controlling equation.

Depending on the hydraulic characteristics of the culvert, there may be certain water surface elevations where the potential flow through the riser exceeds the capacity of the culvert. In such cases, the actual flow through the riser-culvert system is dictated by the capacity of the culvert at those specific water surface elevations. This is referred to as *culvert control,* and the stage-discharge curve (i.e., the rating curve) *must* reflect this condition.

The inlet control nomographs or equations from HDS-5 may be used to check inlet control, but it should be noted that these nomographs were developed for highway culverts; attaching a riser or other clearwell control structure to the end of the culvert will likely alter the flow conditions somewhat. The configuration and relative sizes of the riser and outlet pipe will determine how closely the riser and outlet pipe resemble a highway culvert in terms of hydraulic function.

Multiple-Stage Riser Design

Depending on the design objectives for the facility, the outlet structure may consist of a simple culvert through a dam or it may consist of a drop inlet spillway with a more complicated weir/orifice riser structure. Figure 22.3 shows a riser structure designed to meet several objectives. Table 22.1 shows a spreadsheet set up to calculate the discharge from a multi-stage riser, specifically the one detailed in Figure 22.3.

Orifices: Columns Q1 and Q2 represent the discharge through the 6-inch-diameter and 12-inch-diameter orifices, respectively. The discharge is computed using Equation 22.4.

Column Q3 is the discharge through the top of the riser as computed using Equation 22.4. This is used as a comparison with Q3 of the weir to determine whether the spillway is under orifice flow or weir flow control.

For example, the discharge through each orifice for water surface elevation of 111 feet is:

$$Q_1 = (0.6)(0.196)\sqrt{2g(111 - 100.75)} = 3.0 \text{ cfs} \tag{22.6}$$

$$Q_2 = (0.6)(0.785)\sqrt{2g(111 - 105.5)} = 8.9 \text{ cfs}$$

$$Q_3 = (0.6)(28.27)\sqrt{2g(111 - 110)} = 136.1 \text{ cfs}$$

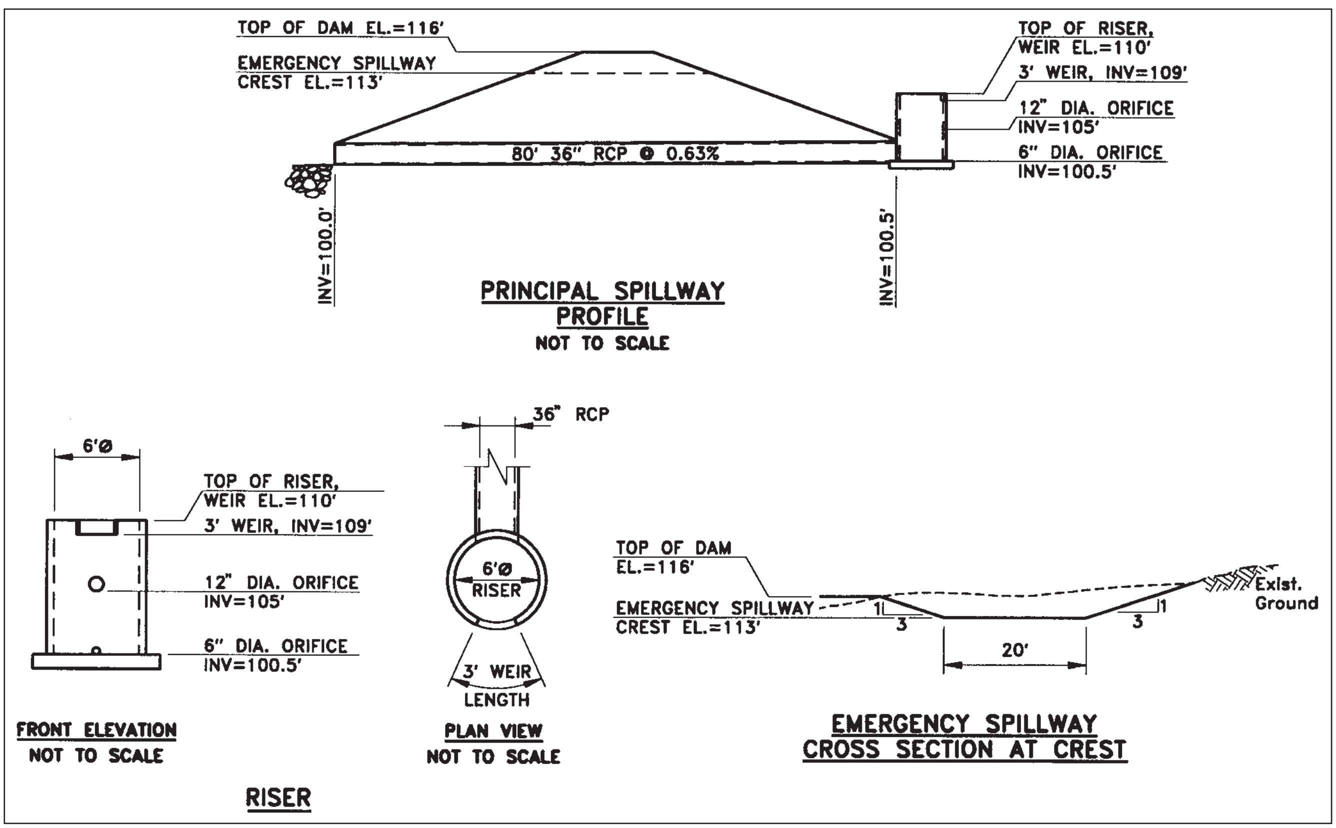


FIGURE 22.3 Riser structure schematic details.

TABLE 22.1 Spillway Rating Curve

PROJECT: EXAMPLE RATING CURVE

ENGINEER/DATE: GLC/11-19-03

ORIFICE FLOW

Orifice No.	Centroid Elev.	Area	C	Description
1	100.75	0.196	0.6	6″ dia. orifice
2	105.5	0.785	0.6	12″ dia. orifice
3 (riser top)	110	28.274	0.6	72″ dia. riser

WEIR FLOW

Weir No.	Crest Elev.	Length	C
1	109	3	3
2			
3 (riser top)	110	15.850	3

EMERGENCY SPILLWAY FLOW

Crest Elev. = 113
Width = 20
Z = 3
C =

CULVERT RATING CURVE
SIZE: 36″ DIA. RCP

Elevation	Discharge
100.5	0
102.6	20
103.8	40
105.55	60
108.53	80
112.07	100
114.06	110
116.18	120
118.08	130
120.11	140

	Orifices			Weirs								
Elev.	Q_1	Q_2	Q_3	Q_1	Q_2	Q_3	Riser Flow	Culvert Capacity	Q_{PSW} (Control)	Q_{ESW}	Total Flow	Comments
100.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
102	1.1	0.0	0.0	0.0	0.0	0.0	1.1	14.3	1.1	0.0	1.1	
103	1.4	0.0	0.0	0.0	0.0	0.0	1.4	26.7	1.4	0.0	1.4	
104	1.7	0.0	0.0	0.0	0.0	0.0	1.7	42.3	1.7	0.0	1.7	
105	1.9	0.0	0.0	0.0	0.0	0.0	1.9	53.7	1.9	0.0	1.9	
107	2.4	4.6	0.0	0.0	0.0	0.0	7.0	69.7	7.0	0.0	7.0	
108	2.5	6.0	0.0	0.0	0.0	0.0	8.5	76.4	8.5	0.0	8.5	
109	2.7	7.1	0.0	0.0	0.0	0.0	9.8	82.7	9.8	0.0	9.8	
109.5	2.8	7.6	0.0	3.2	0.0	0.0	13.5	85.5	13.5	0.0	13.5	
110	2.9	8.0	0.0	9.0	0.0	0.0	19.9	88.3	19.9	0.0	19.9	
110.5	3.0	8.5	96.3	16.5	0.0	16.8	44.8	91.1	44.8	0.0	44.8	
111	3.0	8.9	136.1	25.5	0.0	47.5	84.9	94.0	84.9	0.0	84.9	
111.5	3.1	9.3	166.7	35.6	0.0	87.4	135.3	96.8	96.8	0.0	96.8	culvert control
112	3.2	9.6	192.5	46.8	0.0	134.5	194.1	99.6	99.6	0.0	99.6	culvert control
113	3.3	10.4	235.8	72.0	0.0	247.1	249.5	104.7	104.7	0.0	104.7	culvert control
113.5	3.4	10.7	254.7	85.9	0.0	311.3	268.8	107.2	107.2	22.9	130.1	culvert control

TABLE 22.1 (*Continued*)

	Orifices			Weirs			Riser	Culvert	Q_{PSW}		Total	
Elev.	Q_1	Q_2	Q_3	Q_1	Q_2	Q_3	Flow	Capacity	(Control)	Q_{ESW}	Flow	Comments
114	3.4	11.0	272.3	100.6	0.0	380.4	286.7	109.7	109.7	68.0	177.7	culvert control
114.5	3.5	11.3	288.8	116.1	0.0	453.9	303.6	112.1	112.1	130.9	242.9	culvert control
115	3.6	11.7	304.4	132.3	0.0	531.6	319.6	114.4	114.4	210.6	325.0	culvert control
116	3.7	12.3	333.5	166.7	0.0	698.8	349.4	119.2	119.2	420.8	539.9	culvert control
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

Weir: Columns Q1 and Q2 are the discharge through weirs at elevations below the top of the riser (in this case, there is no weir for Q2 column). The discharge is computed using Equation 22.5. Q3 is the discharge over the riser crest as computed using Equation 22.5. As an example, the weir discharges for a water surface elevation of 111 feet are:

$$Q_1 = (3)(3)(111 - 109)^{3/2} = 25.5 \text{ cfs} \tag{22.7}$$

$$Q_3 = (3)(15.85)(111 - 110)^{3/2} = 47.5 \text{ cfs}$$

Riser flow is the total discharge through the riser without consideration of culvert capacity. The riser is assumed to act as either orifice control or weir control, depending on the discharges computed for Q_3 (orifice) and Q_3 (weir). The lesser of these values dictates the type of control. If Q_3 (orifice) is less than Q_3 (weir), the total flow through the riser is Q_1 (orifice) + Q_2 (orifice) + Q_3 (orifice). If the top of the riser is weir control, the total flow through the riser is Q_3 (weir) + Q_2 (weir) + Q_3 (weir) + Q_2 (orifice) + Q_3 (orifice). The riser flow for a water surface elevation of 111.0 feet is:

$$\text{Riser flow} = 3.0 + 8.9 + 25.5 + 47.5 = 84.9 \text{ cfs} \tag{22.8}$$

Culvert capacity is the maximum discharge that the culvert can convey for a given water surface (see Chapter 21). The culvert discharge analysis is given in Table 22.2.

Q_{PSW} (discharge through the principal spillway) is the lesser value of either the riser flow column or the culvert capacity column.

Q_{ESW} (discharge through the emergency spillway) is computed using Manning's equation with the control section.

Total flow is the sum of columns Q_{PSW} and Q_{ESW}.

To summarize the preceding discussion, the spillway system consists of the principal spillway (culvert and riser) and the emergency spillway. The total flow through the system is the sum of the principal and emergency spillway flows. The flow through the principal spillway depends on the controlling component—either riser or culvert. The greatest flow through the system can be no greater than the capacity of any single component for the given water surface elevation. For example, at elevation 110, the flow through the riser is 19.9 cfs while the capacity of the culvert is 88.3 cfs. The culvert would convey 88.3 cfs, *if* the riser structure were not there to limit the flow to the culvert. At elevation 111.5, the reverse is true. The potential flow through the riser is 135.3 cfs while the capacity of the culvert is 96.8 cfs. Since the culvert is the limiting component, the culvert controls.

Note that the flow through the emergency spillway begins at elevation 113.0. The total flow through the system is then the sum of the flow of the controlling component of the principal spillway (riser or culvert) plus the flow through the emergency spillway. The composite rating curve of Figure 22.4 is obtained from the last column of Table 22.2. This curve represents the combined hydraulic effects of the individual spillway components.

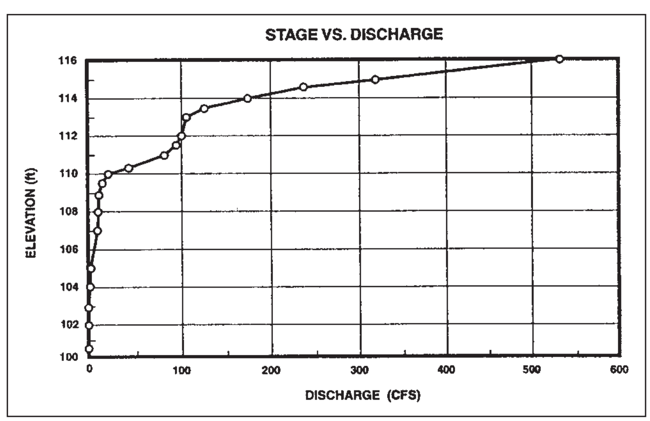


Figure 22.4 Typical spillway rating curve.

TABLE 22.2 Discharge through the Culvert

PROJECT: EXAMPLE RATING CURVE | **STATION:** | **SHEET:** | **CULVERT DESIGN FORM** | **DESIGNER/DATE: GLC/11-19-93**

HYDROLOGICAL DATA

METHOD: RATIONAL
DRAINAGE AREA: 40 ACRES

DESIGN FLOWS/TAILWATER

R.I. (YEARS)	FLOW (CFS)	TW (FT)
	0	100
	20	101
	40	102
	80	104
	120	106
	160	106.5
	200	107
	250	107.2
	300	107.3
	400	107.4
	600	107.5

CULVERT TYPE: RCP
ENT. TYPE: SQ. EDGE WITH HEADWALLS

NO. OF PIPES = 1
DIAMETER = 3

MANNING'S $n = 0.013$

$K_e = 0.7$

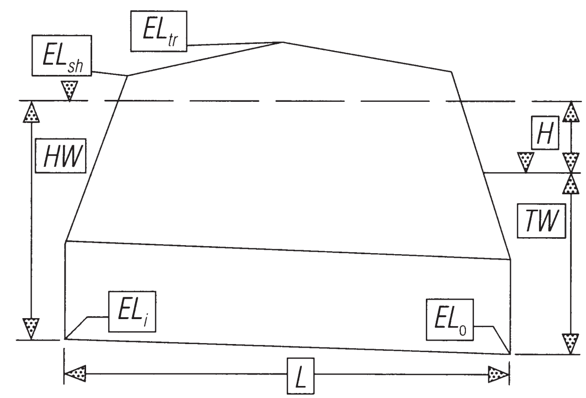
$EL_i = 100.5$

$EL_0 = 100$

$EL_{tr} = 116$ top of dam elev.

$EL_{sh} = 113$ emer spillway crest

$L = 80$



HEADWATER CALCULATIONS

Culvert Description: Material-Shape-Size Entrance	Total Flow Q (CFS)	Flow per Barrel Q/N	Inlet Control: HW_i/D[1]	Inlet Control: HW_i[2]	Inlet Control: $EL(_{HI})$[3]	Outlet Control: TW[4]	Outlet Control: D_c	Outlet Control: $\frac{D_c + D}{2}$	Outlet Control: H_0[5]	Outlet Control: K_E	Outlet Control: H[6]	Outlet Control: $EL(H_0)$[7]	Control HW Elevation	Approximate Outlet Velocity	Comments
1,3′ dia. RCP, sq. edge with headwalls	20	20	0.70	2.10	102.60	1	1.45	2.23	2.23	0.7	0.28	102.51	102.60	5.90	I.C.
″	30	30	0.90	2.70	103.20	1.5	1.80	2.40	2.40	0.7	0.64	103.03	103.20	6.79	I.C.
″	40	40	1.10	3.30	103.80	2	2.08	2.54	2.54	0.7	1.13	103.67	103.80	7.65	I.C.

″	50	50	1.33	4.00	104.50	2.5	2.32	2.66	2.66	0.7	1.77	104.43	104.50	7.94		I.C.
″	60	60	1.62	4.85	105.35	3	2.53	2.76	3.00	0.7	2.55	105.55	105.55	8.49		O.C.
″	70	70	1.96	5.88	106.38	3.5	2.68	2.84	3.50	0.7	3.46	106.96	106.96	9.90		O.C.
″	80	80	2.36	7.08	107.58	4	2.78	2.89	4.00	0.7	4.53	108.53	108.53	11.32		O.C.
″	90	90	2.82	8.45	108.95	4.5	2.86	2.93	4.50	0.7	5.73	110.23	110.23	12.73		O.C.
″	100	100	3.32	9.97	110.47	5	2.90	2.95	5.00	0.7	7.07	112.07	112.07	14.15		O.C.
″	110	110	3.88	11.63	112.13	5.5	2.93	2.97	5.50	0.7	8.56	114.06	114.06	15.56	O.C.	RD.O.T
″	120	120	4.48	13.45	113.95	6	2.95	2.98	6.00	0.7	10.18	116.18	116.18	16.98	O.C.	RD.O.T.
″	130	130	5.16	15.47	115.97	6.125	2.97	2.98	6.13	0.7	11.95	118.08	118.08	18.39	O.C.	RD.O.T.
″	140	140	5.92	17.75	118.25	6.25	2.97	2.99	6.25	0.7	13.86	120.11	120.11	19.81	O.C.	RD.O.T.
″	150	150	6.81	20.43	120.93	6.375	2.98	2.99	6.38	0.7	15.91	122.29	122.29	21.22	O.C.	RD.O.T.
″	160	160	7.89	23.68	124.18	6.5	2.98	2.99	6.50	0.7	18.10	124.60	124.60	22.64	O.C.	RD.O.T.

[1] HW_i based on plynomial best-fit equations from the FHA publication entitled *Calculator Design Series* #3.
[2] HW_i may not be accurate for values <0.5D and >4.5D.
[3] $EL(hi) = HW_i + EL_i$ (invert of inlet control section).
[4] TW based on downstream control or flow depth in channel.
[5] h_o = TW or $(d_c + D)/2$, whichever is greater.
[6] $H = (1 + K_e (n\hat{}\ 2L)/R\hat{}\ 1.33) V\hat{}\ 2/2g$.
[7] $EL(ho) = El_0 + H + h_0$.

QUALITY MANAGEMENT

The Federal Water Pollution Control Act Amendments of 1972 and as amended in 1977, commonly known as the Clean Water Act (CWA), regulate the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters. When first enacted, the Clean Water Act was primarily aimed at point-source discharges. However as point-source discharges decreased, the awareness of the detrimental effects from non-point-source discharges increased. Non-point-source discharges are, as the name implies, pollutant discharges emanating from a dispersed area. Figure 22.5 illustrates some of the nonpoint sources. One of the difficulties with standardizing and implementing specific controls for nonpoint sources of pollution is that many of the sources are transient with respect to time.

In 1978, the EPA provided funding and guidance to a five-year study called the Nationwide Urban Runoff Program (NURP). NURP studied the runoff from commercial and residential areas across the United States. These studies concluded that the affects of urban runoff on receiving water quality are highly site specific. They depend on the type, size, and hydrology of the water body, the characteristics of the runoff quantity and quality, the designated beneficial use of the receiving water, and the concentration levels of the specific pollutants that affect that use. Certain types of water bodies are more vulnerable to non-point-source pollution than others. For example, lakes, reservoirs, and estuaries, which have long residence times, may be subject to accelerated eutrophication because pollutants and sediment may be retained, leading to nutrient buildup.

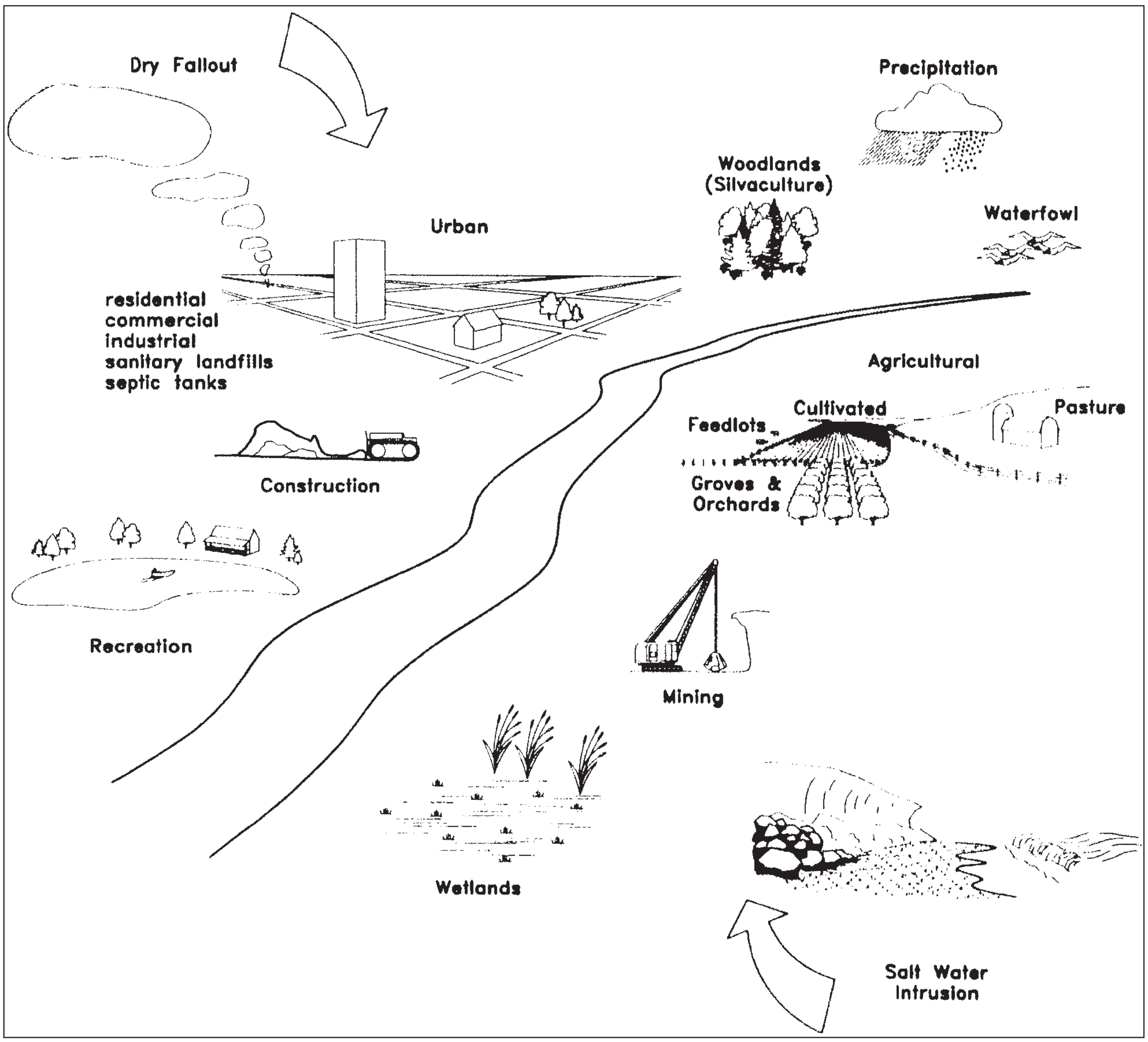


FIGURE 22.5 Nonpoint pollutant sources. (Adapted from Wanielista, Martin P. *Stormwater Management.* New York: John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.)

Types of NPS Pollutants

Non-point-source (NPS) pollutants include sediments, oxygen demand, bacteria, nutrients, metals, and other toxic chemicals. In identifying the source and the type of pollutant, the engineer is better able to recommend a suitable BMP and its appropriate placement in context of the site and outfall. The national distribution of the following described selected primary types of NPS pollutants is shown in Figure 22.6.

Sediment is one of the largest contributors to NPS pollution by volume. Too much sediment in the receiving waters may cause fish gills to clog; reduce the size of spawning areas; block sunlight, preventing plant growth; reduce organism species and numbers because of food-chain perturbations; and reduce aesthetic values. Construction sites and agricultural areas are primary generators of sediment.

In terms of *oxygen demand,* free oxygen or dissolved oxygen (DO) is necessary in water to maintain aquatic life. DO is an indicator of the health of lakes and streams. If the oxygen-demanding bacteria exceed the oxygen-replenishing algae, the DO will be depleted. DO is consumed by microorganisms as they decompose organic matter. A low-DO can lead to fish kills and to a reduction in aesthetic values.

Common bacteria are coliform, fecal coliform, and specific pathogens, such as shigella, salmonella, and clostridium. Bacteria, in addition to causing a low DO, may be a health hazard. Generally, surface waters are tested for coliform bacteria. While coliform bacteria are not pathogenic, their presence is an indicator that more pathogenic organisms may be present. Sources include animal droppings, garbage, and sanitary wastewaters.

Nutrients are chemicals that stimulate the growth of algae and water plants, which in excess can contribute to the degradation of lake and stream water quality. Micronutrients are nutrients that are needed in very small quantities. Nitrogen and phosphorus are the most common micronutrients. Water quality problems that result from excess nutrients include algal scums, water discoloration, odors, toxic releases, and overgrowth of plants. Sources include gardens, lawns, golf courses, and other areas that are frequently fertilized.

Metals are widely varied and may be present in stormwater. An ingestion of excess metals may cause health problems and birth defects; this is a primary concern in waters used for recreational purposes and in terms of fish and seafood cultivation. The most common metals in urban runoff are lead (Pb), copper (Cu), and zinc (Zn). Sources include flashing, gutters, downspouts, brake linings from vehicles, paints, catalytic converters, and tires.

Other toxic chemicals found in surface waters may include phenols and creosols (wood preservatives), pesticides and herbicides, oils and greases, petroleum products, and many other manufactured chemicals.

Estimating Pollutant Loads and Concentrations

As a result of laws such as the Clean Water Act, designers are often required to reduce the amount of pollutants leaving a development area to some percentage of predevelopment levels. This generally involves quantifying the pre- and post-development pollutant loads from some key pollutants (frequently nutrients). The engineer then attempts to reduce the postdevelopment loads by implementing some form of best management practice (BMP).

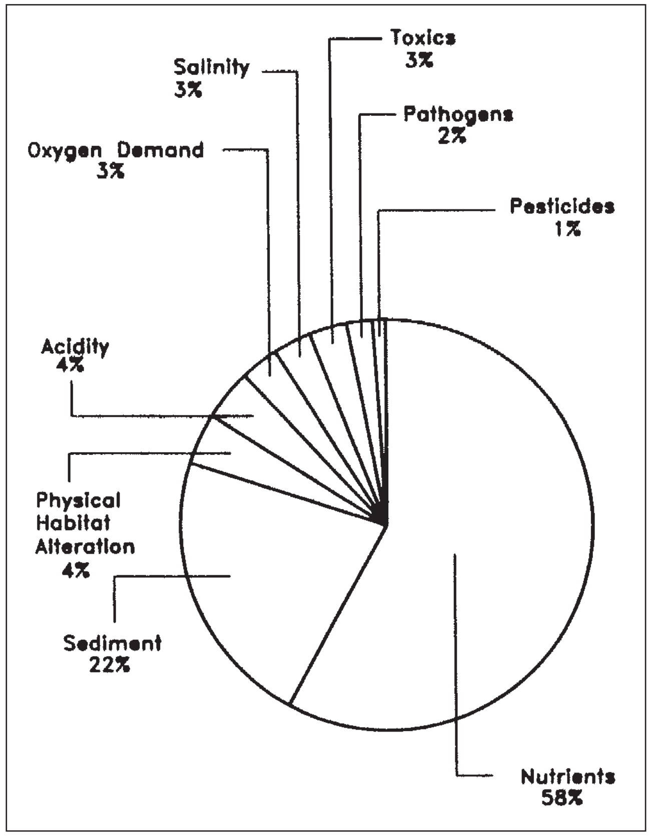


Figure 22.6 Primary types of NPS pollution in lakes in the United States. (Courtesy of Engineers & Surveyors Institute Northern Virginia)

There are several methods for estimating the quantity of pollutants generated from a site. One method involves using the event mean concentration to calculate the mass of runoff pollutants for each rainfall event and then summing the average number of rainfall events per year. Other methods for estimating the pollutant runoff from nonpoint sources involve the use of USGS regression equations.

Event mean concentration (EMC) is the average concentration of pollutants per storm event. The mass of runoff pollutants for each storm event is the product of event mean concentration and rainfall excess, as given in Equation 22.9.

$$L = R \times \mathrm{EMC} \tag{22.9}$$

where L = the total mass load per rainfall event (mass/rainfall event), R = runoff per average storm event (volume), and EMC = event mean concentration (mass/volume).

To determine the yearly mass load of pollutants, L is multiplied by the average number of storm events per year. Table 22.3 lists the median EMCs by land use category.

A variation of the EMC, or the mass-loading principal, is outlined in Schueller (1987). This methodology calculates

TABLE 22.3 Median EMCs for All Sites by Land Use Category

Pollutant	Residential Median	Residential CV	Mixed Median	Mixed CV	Commercial Median	Commercial CV	Open/Nonurban Median	Open/Nonurban CV
BOD (mg/L)	10.0	0.41	7.8	0.52	9.3	0.31	—	—
COD (mg/L)	73	0.55	65.0	0.58	57.0	0.39	40	0.78
TSS (mg/L)	101	0.96	67.0	1.14	69.0	0.35	70	2.92
Total lead (μg/L)	144	0.75	114.0	1.35	104.0	0.68	30	1.52
Total copper (μg/L)	33	0.99	27.0	1.32	29.0	0.81	—	—
Total zinc (μg/L)	135	0.84	154.0	0.78	226.0	1.07	195	0.66
Total Kjeldahl nitrogen (μg/L)	1,900	0.73	1,288.0	0.50	1,179.0	0.43	965	1.00
$NO_2 - N + NO_3 - N$ (μg/L)	736	0.83	558.0	0.67	572.0	0.48	543	0.91
Total P (μg/L)	383	0.69	263.0	0.75	201.0	0.67	121	1.66
Soluble P (μg/L)	143	0.46	56.0	0.75	80.0	0.71	26	2.11

(*Source:* Wanielista, Martin P. *Stormwater Management.* New York: John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.)

TABLE 22.4 Urban *C* Values for Use with the Simple Method (mg/L)

Pollutant	New Suburban NURP Sites (Washington, DC)	Older Urban Areas (Baltimore, MD)	Central Business District (Washington, DC)	National NURP Study Average	Hardwood Forest (Northern VA)	National Urban Highway Runoff
Phosphorus						
Total	0.26	1.08	—	0.46	0.15	—
Ortho	0.12	0.26	1.01	—	0.02	—
Soluble	0.16	—	—	0.16	0.04	0.59
Organic	0.10	0.82	—	0.13	0.11	—
Nitrogen						
Total	2.00	13.6	2.17	3.31	0.78	—
Nitrate	0.48	8.9	0.84	0.96	0.17	—
Ammonia	0.26	1.1	—	—	0.07	—
Organic	1.25	—	—	—	0.54	—
TKN	1.51	7.2	1.49	2.35	0.61	2.72
COD	35.6	163.0	—	90.8	>40.0	124.0
BOD (5-day)	5.1	—	36.0	11.9	—	—
Metals						
Zinc	0.037	0.397	0.250	0.176	—	0.380
Lead	0.018	0.389	0.370	0.180	—	0.550
Copper	—	0.105	—	0.047	—	—

(*Source:* Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226. 202/962-3256) pollutant yield, in pounds, based on the concentration of that pollutant per volume of stormwater runoff. Thus, knowing the concentration of any waterborne pollutant in mass per volume of water, and knowing the volume of stormwater runoff to be expected from a site over any described period of time, a corresponding pollutant export value is easily determined by:

$$L = \left(\frac{(P)(P_j)(R_v)}{12}\right) CA(2.72) \tag{22.10}$$

where P = rainfall depth in inches over the desired time interval over which the loading estimates are desired. For annual loading estimates, P is the average annual rainfall. For a load estimate for a specific design storm, P is the rainfall for that storm; P_j = correction factor for P that accounts for storms that produce no measurable runoff. For individual storms $P_j = 1$; R_v = a runoff coefficient to convert rainfall to runoff, equal to the ratio of the storm runoff to storm rainfall. NURP data from 44 small urban catchments shows that $R_v = 0.05 + 0.009(I)$, where I is the percent of site imperviousness; C = flow weighted mean concentration of the pollutant in urban runoff in mg/L, as given in Table 22.4; and A = total site area in acres.

This method is referred to as the *simple method* for obvious reasons. Limitations on the use of this method include:

- This method estimates pollutant loads from storm runoff. Base flow and associated pollutants are not considered in the equation. Base flow for small sites is negligible; however, in larger, low-density watersheds, base flow and the associated nutrients can be as high as or higher than the pollutants in storm runoff.
- The data for the simple method is predominantly from recently stabilized suburban watersheds. Consequently, reliable C values for sites such as construction areas, industrial areas, rural areas, and agriculture areas may not exist.
- Larger, more complex watersheds may need to be analyzed with more sophisticated models. The precision of the simple method is such that it cannot be used to distinguish slight variations in developments.

BEST MANAGEMENT PRACTICES

Best management practices (BMPs) are policies, practices, procedures, or structures implemented to mitigate the adverse impacts to surface water quality resulting from development. In terms of land development engineering, either structural or nonstructural BMPs may be utilized. Structural BMPs include such controls as extended detention ponds, dry ponds, infiltration trenches, shallow marshes/wetlands, porous pavements, and water quality inlets. Nonstructural BMPs include street cleaning, fertilizer application control, and certain vegetative practices such as grass swales and filter strips.

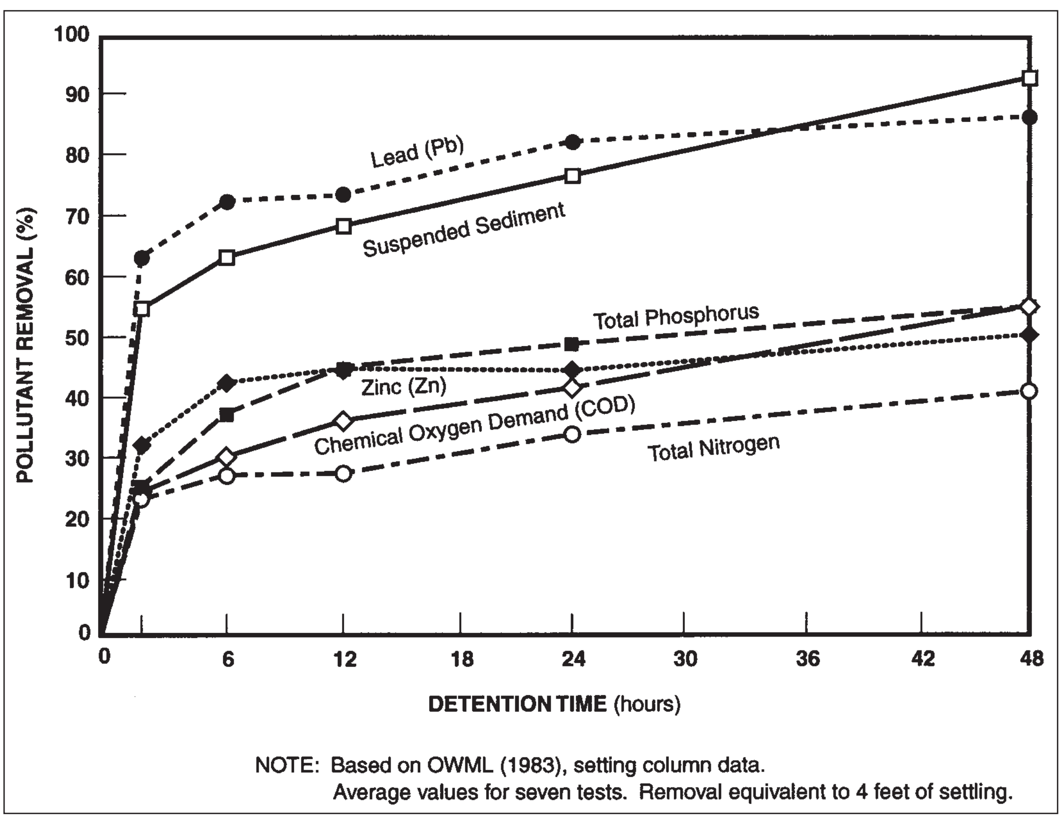


FIGURE 22.7 Removal rate versus detention time for selected pollutants. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

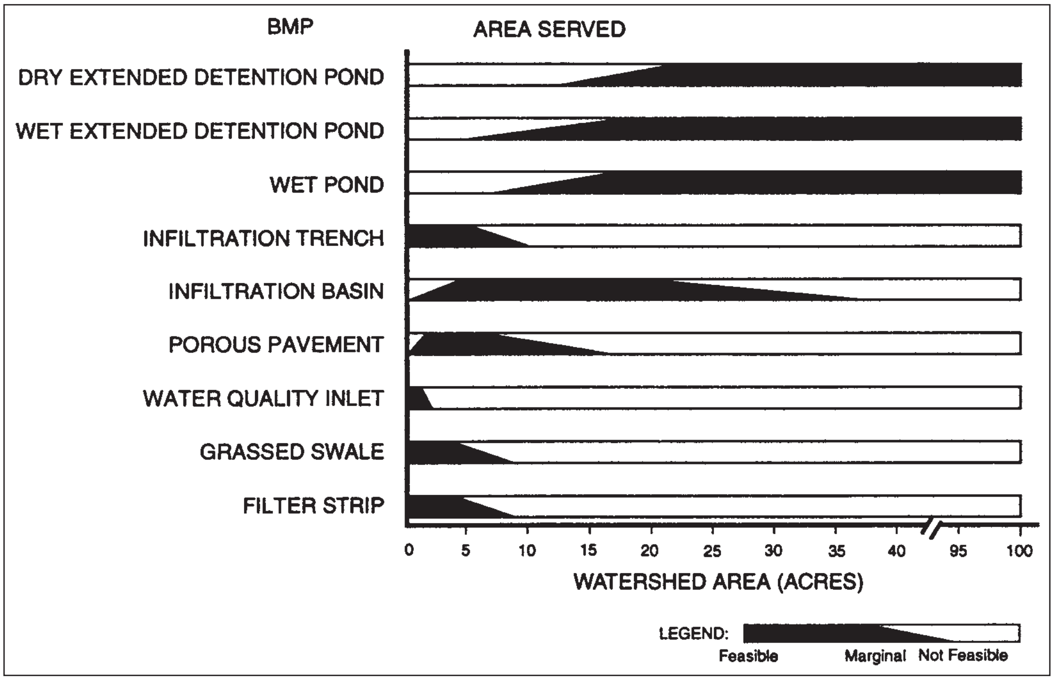


FIGURE 22.8 Watershed area restrictions for BMPs. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

The primary mechanisms for pollutant removal in BMP facilities are settling of particulate pollutants and sediments and, to a lesser degree, infiltration of soluble nutrients through the soil profile and biological and chemical stabilization of nutrients. Settling column experiments have been performed to estimate the removal of pollutants from urban runoff. Figure 22.7 (Scheuler, 1987), illustrating the percentage of pollutant removal with time, shows that each curve roughly parallels that of suspended sediments. Thus, suspended sediment removal frequently forms the basis of BMP designs. It should be noted that the efficiency of removal of pollutants is related to the particle size of the pol-

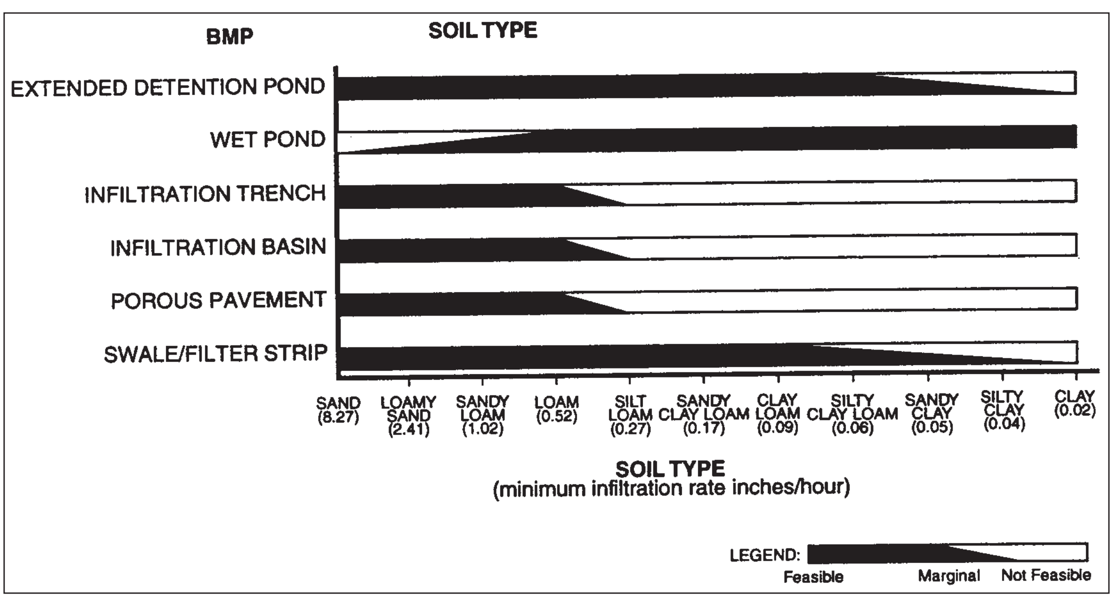


FIGURE 22.9 Soil permeability restrictions for BMPs. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

BMP	Slope	High Water Table	Close to Bedrock	Proximity to Foundations	Space Consumption	Maximum Depth	Restricted Land Uses	High Sediment Input	Thermal Impacts
Extended Detention Pond	●	●	●	●	○	●	●	●	●
Wet Pond	●	●	●	●	○	○	●	●	○
Infiltration Trench	○	○	○	○	●	○	●	○	●
Infiltration Basin	●	○	○	●	●	○	●	○	●
Porous Pavement	○	○	○	○	○	○	○	○	●
Water Quality Inlet	●	●	○	○	●	○	○	○	●
Grassed Swale	○	○	●	●	●	●	○	○	●
Filter Strip	●	●	●	●	●	●	●	○	●

LEGEND
● May preclude the use of a BMP
● Can be overcome with careful site design
○ Generally not a restriction

FIGURE 22.10 Other common restrictions on BMPs. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

lutants (which affects the settling velocity), the velocity of flow through the storage area, and the depth and total storage volume available (related to the hydraulic residence time, or the length of time during which settling may occur). Since the majority of pollutants are normally washed off the land surface in the first flush, or the initial portion of runoff from a storm event, most BMPs are designed to capture or treat the first flush of runoff volume.

The selection for and effectiveness of a BMP facility depends on numerous site conditions such as climate, watershed size, soil permeability, ground slope, subsurface conditions (e.g., bedrock and ground water), and land use, to name a few. Figures 22.8 through 22.10 recommend various restrictions to specific BMP facilities.

Another factor influencing the design and selection of BMPs is the governing criteria for efficiency. Local criteria prescribe the allowable postdevelopment pollutant loading. Typical policies range from "no net gains" (i.e., postdevelopment pollutant loading must be less than or equal to predevelopment pollutant loads) to reducing the postdevelopment pollutant loads to a specific percentage of the predeveloped conditions. Other criteria may set the allowable loadings on a site-by-site basis based, perhaps, on location within a water or sewer district. The pollutant removal efficiencies shown in Figure 22.11 might be considered for ideal conditions. These values are to be used as a guide, since some studies have shown substantial differences from these efficiencies. Of the types of BMP measures listed in Figure 22.11, the most effective types of facilities, according to a study done in Maryland (Galli, 1982), are the wet ponds, extended detention ponds, artificial marshes, and infiltration trenches (see Table 22.5).

TYPES OF STORMWATER MANAGEMENT FACILITIES

What follows is a series of detailed fact sheets on the various types of stormwater management facilities (adapted primarily from Chapter 19, "New Development and Redevelopment Program," Appendix II of the CO DOT Drainage Design Manual). These facilities have been broadly categorized by their type and include a description of the facility, guidelines on how to properly select or apply a design alternative, and general design criteria for their successful implementation.

As discussed earlier in this chapter, the requirements of stormwater management include water quantity as well as water quality control. Depending on the jurisdiction that you are working in, these requirements will change. Historically, stormwater management was achieved through an end-of-the-line solution (detention facility, regional pond). This philosophy is changing, as we now design our stormwater BMPs to treat rainfall and runoff at the source and replicate the predevelopment hydrologic characteristics (decreasing the peak rate of runoff and recharging ground water supplies). By treating runoff at the source you often decentralize the treatment of stormwater runoff by creating several smaller, more integrated treatment systems (bioretention, sandfilters, dryswales, etc.). These smaller facilities may be

BMP/Design	SUSPENDED SEDIMENT	TOTAL PHOSPHORUS	TOTAL NITROGEN	OXYGEN DEMAND	TRACE METALS	BACTERIA	OVERALL REMOVAL CAPABILITY
EXTENDED DETENTION POND							
DESIGN 1	◕	◔	◔	◔	◑	⊗	MODERATE
DESIGN 2	●	◑	◔	◑	◕	⊗	MODERATE
DESIGN 3	●	◕	◑	◑	◕	⊗	HIGH
WET POND							
DESIGN 4	◕	◑	◔	◔	◔	⊗	MODERATE
DESIGN 5	◕	◑	◔	◔	◕	⊗	MODERATE
DESIGN 6	●	◕	◑	◑	◕	⊗	HIGH
INFILTRATION TRENCH							
DESIGN 7	◕	◑	◑	◕	◕	◕	MODERATE
DESIGN 8	●	◑	◑	◕	●	◕	HIGH
DESIGN 9	●	◕	◕	●	●	●	HIGH
INFILTRATION BASIN							
DESIGN 7	◕	◑	◑	◕	◑	◕	MODERATE
DESIGN 8	●	◑	◑	◕	●	◕	HIGH
DESIGN 9	●	◕	◕	●	●	●	HIGH
POROUS PAVEMENT							
DESIGN 7	◑	◕	◑	◕	◑	◕	MODERATE
DESIGN 8	●	◕	◕	◕	●	●	HIGH
DESIGN 9	●	◕	◕	●	●	●	HIGH
WATER QUALITY INLET							
DESIGN 10	○	⊗	⊗	⊗	⊗	⊗	LOW
FILTER STRIP							
DESIGN 11	◔	○	○	○	◔	⊗	LOW
DESIGN 12	●	◑	◑	◕	●	⊗	MODERATE
GRASSED SWALE							
DESIGN 13	○	○	○	○	○	⊗	LOW
DESIGN 14	◔	◔	◔	◔	○	⊗	LOW

Design 1: First-flush runoff volume detained for 6-12 hours.
Design 2: Runoff volume produced by 1.0 inch, detained 24 hours.
Design 3: As in Design 2, but with shallow marsh in bottom stage.
Design 4: Permanent pool equal to 0.5 inch storage per impervious acre.
Design 5: Permanent pool equal to 2.5 (Vr); where Vr mean storm runoff.
Design 6: Permanent pool equal to 4.0 (Vr); approx. 2 weeks retention.
Design 7: Facility exfiltrates first-flush; 0.5 inch runoff/impervious acre.
Design 8: Facility exfiltrates one inch runoff volume per impervious acre.
Design 9: Facility exfiltrates all runoff up to the 2 year design storm.
Design 10: 400 cubic feet wet storage per impervious acre.
Design 11: 20 foot wide turf strip.
Design 12: 100 foot wide forested strip, with level spreader.
Design 13: High slope swales, with no check dams.
Design 14: Low gradient swales with check dams.

KEY:
- ○ 0 TO 20% REMOVAL
- ◔ 20 TO 40% REMOVAL
- ◑ 40 TO 60% REMOVAL
- ◕ 60 TO 80% REMOVAL
- ● 80 TO 100% REMOVAL
- ⊗ INSUFFICIENT KNOWLEDGE

FIGURE 22.11 Comparative pollutant removal of urban BMP designs. (Courtesy of Galli, John. 1982. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

TABLE 22.5 Summary: General Attributes of BMP Systems Field Surveyed

Factor	Infiltration Trenches	Porous Pavement and Dry Wells	Infiltration Basins	Grass Filters/ Swales	ED Dry Ponds	Wet Ponds	Artificial Marshes	Pocket Wetlands	Oil/Grit Separators	Dry Ponds
I. BENEFITS										
Downstream channel protection	●	○	○	○	●	◍	◍	◍	○	○
Removal of particulate pollutants	●	○	◍	○	◍	●	○	◍	○	○
Removal of soluble pollutants	●	○	○	○	○	◍	◍	○	○	○
Aquatic/wildlife habitat creation	○	○	○	○	○	◍	◍	○	○	○
Wetland creation	○	○	●	○	○	◍	◍	◍	○	○
Thermal impact protection	●	●	●	○	○	●	○	○	○	○
II. DISADVANTAGES										
Soils limitations	●	●	●	◍	◍	◍	◍	◍	○	◍
Maintenance requirements	●	●	●	◍	●	◍	◍	◍	●	◍
Space consumption	◍	○	●	◍	●	●	●	◍	○	●
Public safety hazards	○	○	●	○	◍	●	●	◍	○	◍
Functional life/reliability*	○	○	○	◍	○	◍	◍	○	○	○

(*Source:* Courtesy of Galli, John. 1982. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland.* Washington, D.C.: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

○ Low

◍ Moderate

● High

* General ability to provide water quality/quantity control benefits for five years or more without regular sediment/trash removal.

able to reduce the size of (or even eliminate the need for) larger detention facilities downstream, as sufficient stormwater management treatment has already been provided through the various upstream integrated practices. Also, from a practical point of view, in many urban areas there simply isn't the space necessary for a large stormwater management pond, so an alternative BMP should be considered. In rural/suburban areas, dry swales, landscaped bioretention, or rain barrels may be more acceptable to the community than a more obtrusive BMP (large pond). The following subsections discuss an array of design alternatives that can be implemented alone or in tandem to meet the requirements of the local jurisdiction or client.

Alternative BMPs

A public education program may be considered a nonstructural BMP. Educating the public about activities that contribute to pollution and about practices that may help to reduce pollution can provide incentive and allow homeowners to be directly involved in reducing NPS pollution and improving water quality. Such practices include the proper use of fertilizers, disposal of used petroleum products, water conservation, litter control, and controls for minimizing erosion from disturbed ground. These most fundamental types of BMPs may only be of limited use in land development engineering but should be recognized as alternatives to be considered for a development or community, along with the following options.

Catch Basin Inserts

Description. Catch basin inserts hang from the opening of a curb inlet or below the grate of an area inlet. These inserts catch debris and other sediment and pollutant particles before they flow downstream. Some inserts have more than one treatment mechanism (i.e., oil absorption areas and sediment trapping sections) and are generally placed in areas where oil/grit separators cannot be used. See Figure 22.12.

Application Guidelines

- Generally, inserts are not suitable for removal of fine particulates such as metals, clays, silts, or nutrients.
- Some inserts are designed with more than one treatment mechanism. One such method is an inner component that contains oil-absorbent materials.
- Inserts can be used in areas where coarse sediments or materials are expected in stormwater.
- They are suitable for sites where substantial amounts of debris are found in stormwater.
- They can be used in areas of unpaved roads or parking areas, construction sites, unpaved industrial sites, and lumberyards.
- Inserts can be used in areas where oil/grit separators cannot be used.

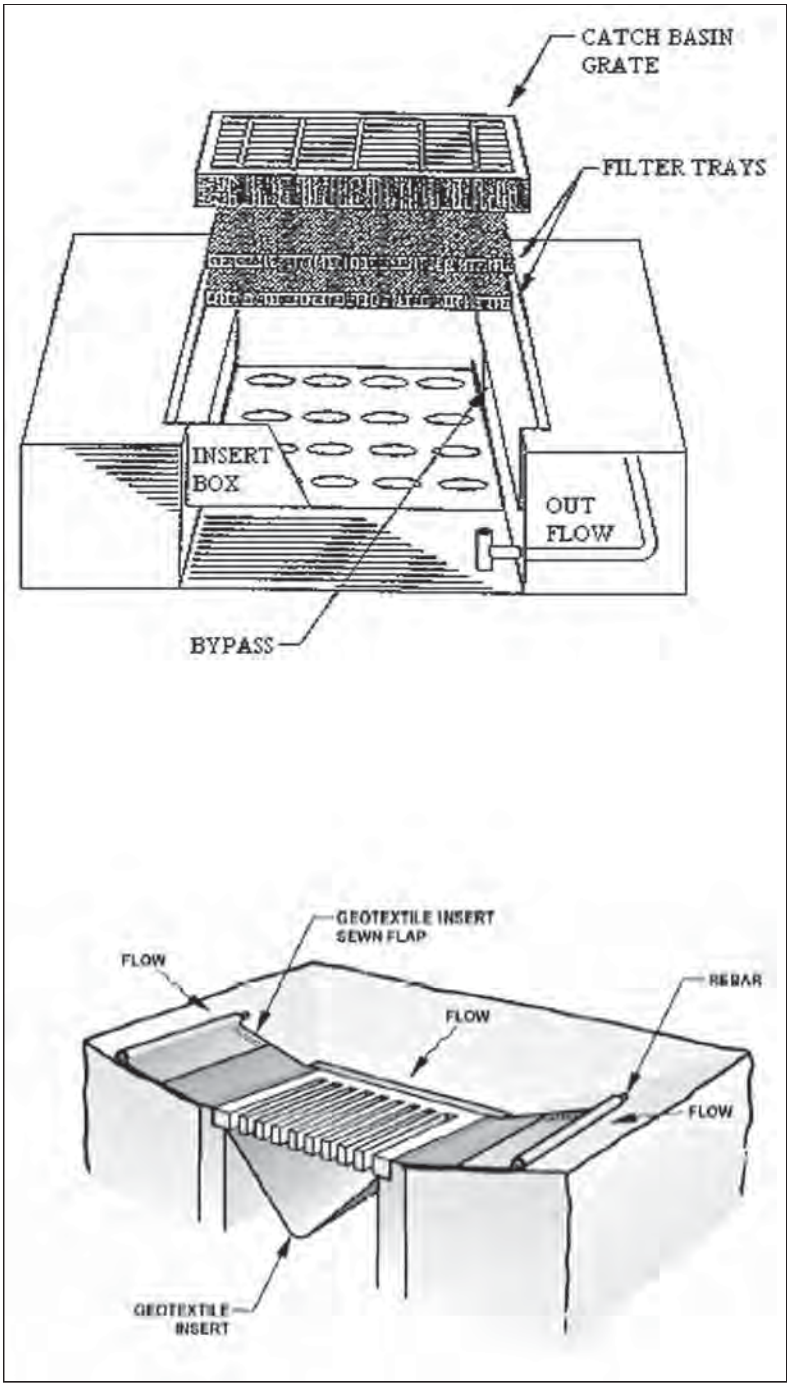


FIGURE 22.12 Catch basin insert options—filter insert or geotextile wrap. (CDOT Drainage Design Manual Appendix II)

- Inserts should have a high-flow bypass to prevent resuspension and washout.
- Inserts have limited ability to remove pollutants and should be used in conjunction with other BMPs.
- They are best suited as pretreatment for sediment and debris removal before flows are conveyed to downstream BMPs.

Basic Design Criteria

- Inserts should be designed for a reasonable design storm (i.e., two-year), based on the characteristics of the site.
- Inserts should not interfere with storm events greater than or equal to the 10-year storm.
- Regular inspection and maintenance are required.
- Inserts should be cleaned after every two or three major storms.
- Maintenance is more intensive for inserts configured to remove oil and grease.
- Street sweeping can be used in conjunction with inserts to reduce maintenance frequency and extend service life.

Sheet Flow to Buffers

Description. A structural BMP used to filter pollutants as stormwater runoff moves to a swale, stream, or other flow area. This BMP protects streams, lakes, and/or wetlands from high concentrations of sediment in runoff. The flows are discharged over the buffer zone, where sediments and other pollutants can be filtered out before the flows reach the natural drainageway. See Figure 22.13.

Application Guidelines

- Zone where stormwater runoff is treated by a natural buffer before it enters a stream or forested area.
- Runoff from pervious and impervious areas is discharged through the buffer.
- The buffer generally consists of grass, meadow, forest, or a mix.
- It is generally used to treat overland flow in the green space of a development site.
- A level spreader or similar BMP can be used along the upstream edge of the buffer zone to enhance treatment.

Basic Design Criteria

- The minimum buffer width is 50 feet and is measured from the bank elevation of the stream.
- The maximum contributing length is 150 feet for pervious surfaces and 75 feet for impervious surfaces.
- Runoff will enter the buffer as sheet flow. If sheet flow cannot be achieved at the edge of the buffer, a level spreader or similar BMP will be used to establish sheet flow.
- The contributing overland slope should be less than 5 percent.
- A buffer is not applicable where rooftop or non-rooftop disconnections are already in place.
- Buffers should be located within conservation easements or other enforceable areas that will ensure future protection of the buffer area.

Street Sweeping

Description. In this BMP, mechanical vehicles are used to physically remove solids and other pollutants from impervious surfaces. New street-sweeping technologies, including vacuum-assisted sweeping, can potentially reduce total annual suspended solids and pollutants up to 80 percent.

Application Guidelines

- Street sweeping is well suited to urban environments where little land is available for structural or sedimentation-based controls.
- It can be used in commercial districts and industrial sites, and in intensely developed areas near receiving waters.
- Consider it for highway applications along road shoulders, rest stops, parking areas, or maintenance yards.
- Best results are achieved when most sophisticated sweepers are used at a weekly to bimonthly frequency, depending on local regulations and conditions.
- This is not a preferred application for the removal of oil and grease.
- Older mechanical sweepers are limited in their ability to remove fine sediment.
- Types of sweepers and practices include vacuum-assisted sweepers, mechanical sweepers, regenerative air sweepers, vacuum-assisted dry sweepers, and tandem sweeping.

Basic Design Criteria

- Sweepers need to be operated at optimum speeds and sweeping patterns, with brushes properly adjusted, for maximum particulate removal from surfaces.
- Generally, 50 percent of particulates can be removed if sweeping is done at least once between storms, with two passes per run. Depending on local traffic conditions and storm frequencies, sweeping may need to be done at more frequent intervals to achieve desired particulate removal.

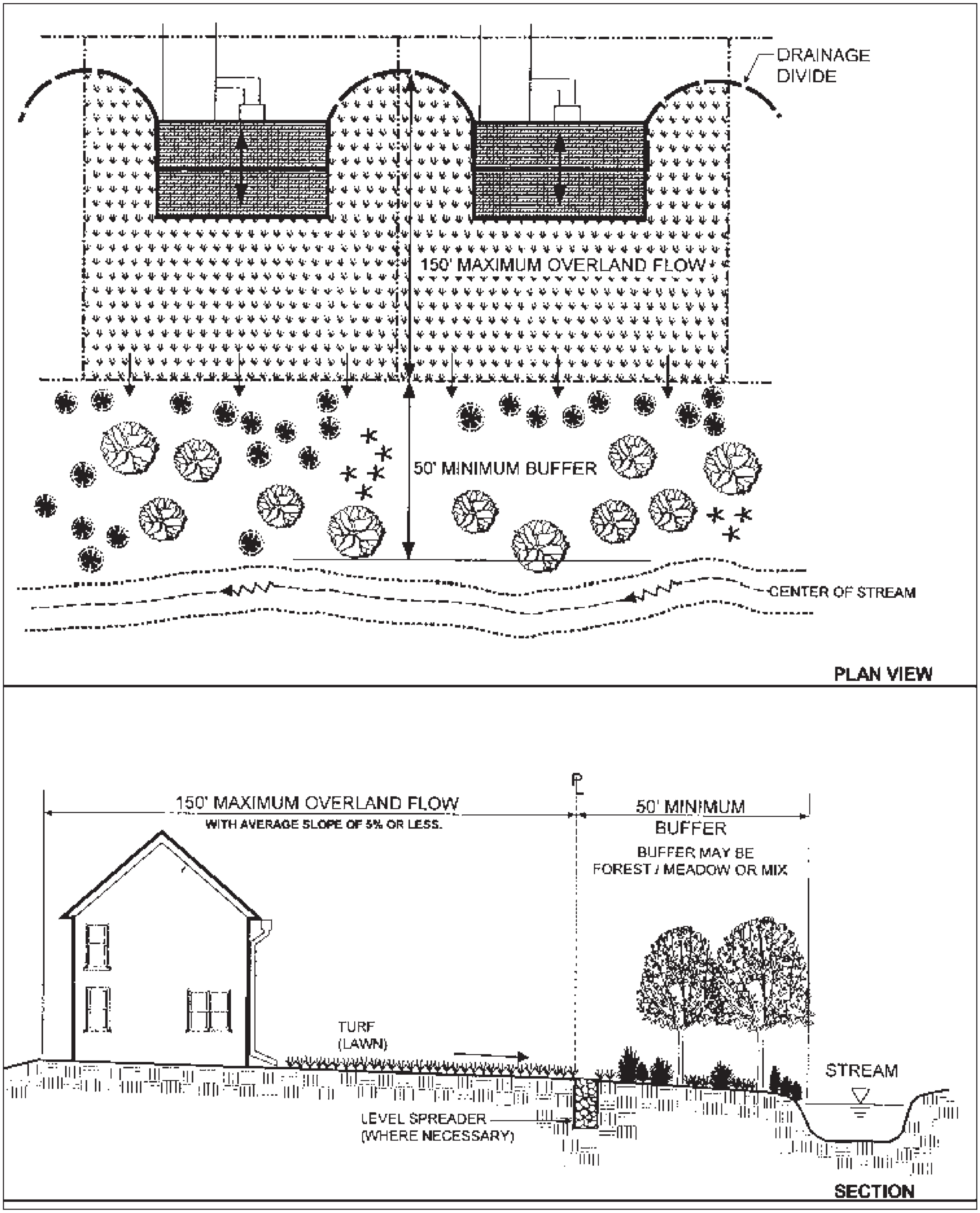


FIGURE 22.13 Sheet flow to buffer detail.

■ Maintenance requirements are greater for certain types of sweepers.

■ Ensure that arrangements are made for the disposal of collected wastes.

■ Street sweeping is more effective if upstream erosion control and stormwater BMPs are implemented, especially at construction sites.

Vegetated Roofs

Description. A quantity and quality control BMP, vegetated roofs, or *greenroofs,* provide stormwater, aesthetic, open space/habitat, and energy-efficiency benefits when utilized as a component of the roofing system. See Figure 22.14. A reduction in the peak rate and volume of runoff occurs through interception and evapotranspiration, while improved water quality is realized through capturing, filtering, and plant uptake. Other benefits include improved heating/cooling within the building itself and reduced heat island effect, and in certain applications (depending on the project goals) habitat creation, noise reduction, and recreational open space. Two types of vegetated roofs exist: extensive and intensive. They are differentiated by media depth, type of plant material, and roof function.

Application Guidelines: General

■ Vegetated roofs are commonly applied to nonresidential structures and may be used on residential applications where roof slopes are not extreme (less than 33 percent).

■ They are most beneficial in urban areas or constrained sites where the bulk of the buildable area is dedicated to the building or structure.

■ Vegetated roofs may be installed as either modular (grid) systems or as a layered application.

FIGURE 22.14 Janelia Farm—Dewberry's complete greenroof planting design services incorporated an international meadow prairie theme along with hardscape design and detailing for the 24 rooftop gardens. Low-impact, drought-resistant plant materials were used throughout.

■ Construction of the vegetated roof must be coordinated with the planting season.

■ Most jurisdictions enforce a coverage requirement (i.e., 90 percent plant establishment within two years) through implementation of a bond.

Basic Design Criteria

General

■ All vegetated roof systems should have the structural roof, a waterproof membrane, a drainage layer, growth media ranging in depth from approximately 3 to 12 inches depending on the type of roof, and plants. Optional cross-sectional components include a root barrier, an insulation layer, a leak detection system, and irrigation. (See Figure 22.15.)

■ Incorporate maintenance access—typically a 1- to 2-foot-wide nonvegetated strip around the perimeter and any roof penetrations.

■ Account for irrigation needs during plant establishment and periods of drought.

■ Provide overflow relief for larger storms.

Extensive

■ Growth medium is typically 3 to 6 inches.

■ Roof slope should be between 2 and 33 percent to ensure drainage and vegetation stabilization.

■ Common plant species include mosses, sedums, herbaceous plants, and grasses (native plants are recommended).

■ Use a C-value of 0.5 or CN of 70 for postdevelopment hydrology.

Intensive

■ The growth medium is typically 6 to 12 inches, and potentially greater depending on the intended use and plant type.

■ Roof slope should be between 2 and 10 percent to ensure drainage and vegetation stabilization.

■ Common plant species include mosses, sedums, herbaceous plants, grasses, shrubs, and small trees (native plants are recommended).

■ Use a C-value of 0.4 or CN of 65 for postdevelopment hydrology.

■ LEED-NC SS Credit 7.2 Heat Island Effect, Roof grants one point toward mitigating the heat island effects of new construction. Installing a vegetated roof on at least 50 percent of the roof is one way to meet this credit.

■ From a LEED certification perspective, there is significant benefit to the use of a greenroof. Beyond the

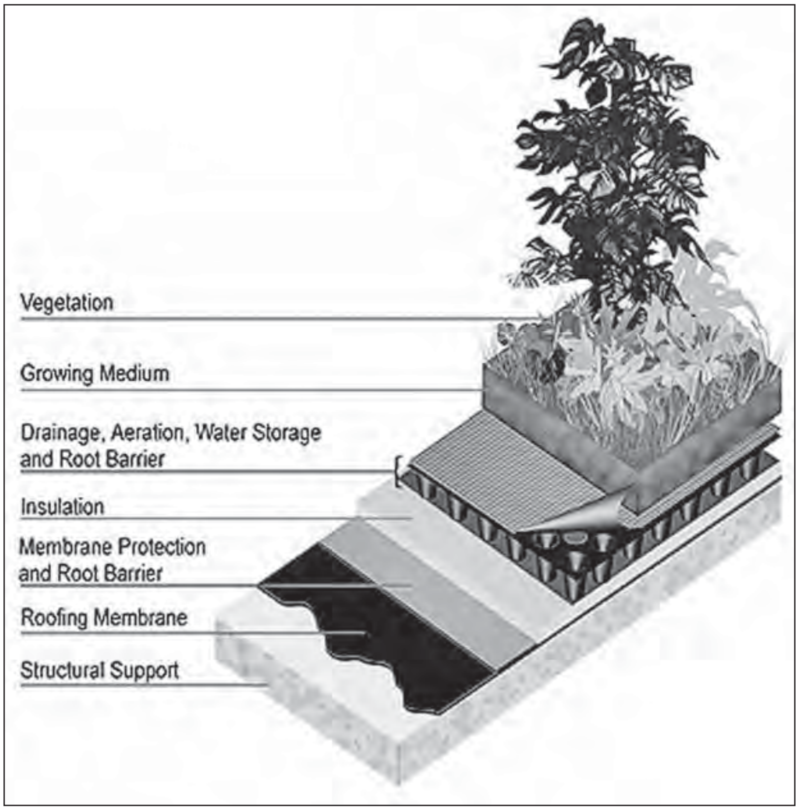


FIGURE 22.15 Detail of a typical greenroof including various design elements anticipated. (American Wick Drain Corporation)

initial LEED-NC SS 7.2 Heat Island Effect, Roof credit, the benefit of greenroofs can be spread among several other credits/measures because of the integrated nature of the LEED system. Greenroofs have the potential of contributing to the attainment of 6 to 16 credits when designed and integrated to the fullest extent. This is a significant amount of credits when pursuing LEED certification for a project and is a strong argument in favor of consideration of greenroofs, in light of their cost.

Structural BMPs

Water Quality Inlet with Oil/Grit Separator

Description. This structural BMP is similar to a standard curb inlet with modifications made to the underground portion of the structure to separate oil and grit into discrete chambers. Generally this BMP consists of a three-chamber system designed to remove heavy particulates and trap hydrocarbons from stormwater runoff. See Figure 22.16.

Application Guidelines

- Inlets are generally used at sites expected to receive heavy vehicular traffic.
- They are also used at sites where oils, grease, and petroleum products could be carried by stormwater.
- Inlets are often placed in parking lots, service stations, or in truck loading areas.
- Inlets can be used to reduce the maintenance required at downstream BMPs.
- Inlets are a multistage underground retention system.
- The upstream chamber traps sediments, the center chamber traps oils and other heavy substances, and the downstream chamber discharges flows.
- Since flows are detained for only a short time, pollutants are not removed as effectively as in facilities that retain runoff for longer periods.
- Although flows are detained for only a short time, inlets can be used as an effective first stage of treatment by removing oil, grease, and sediments from stormwater before the flows enter a larger BMP such as a pond.
- Inlets can be installed in most areas; the drainage area to the inlet is generally less than one acre.

Basic Design Criteria

- Inlets can be installed in any soil or terrain and are best used when they are installed at or near the impervious area that generates stormwater runoff.
- The area above the inlet needs to be large enough for maintenance access.
- The inlet should be designed with a permanent pool approximately 4 feet deep, with a total chamber volume

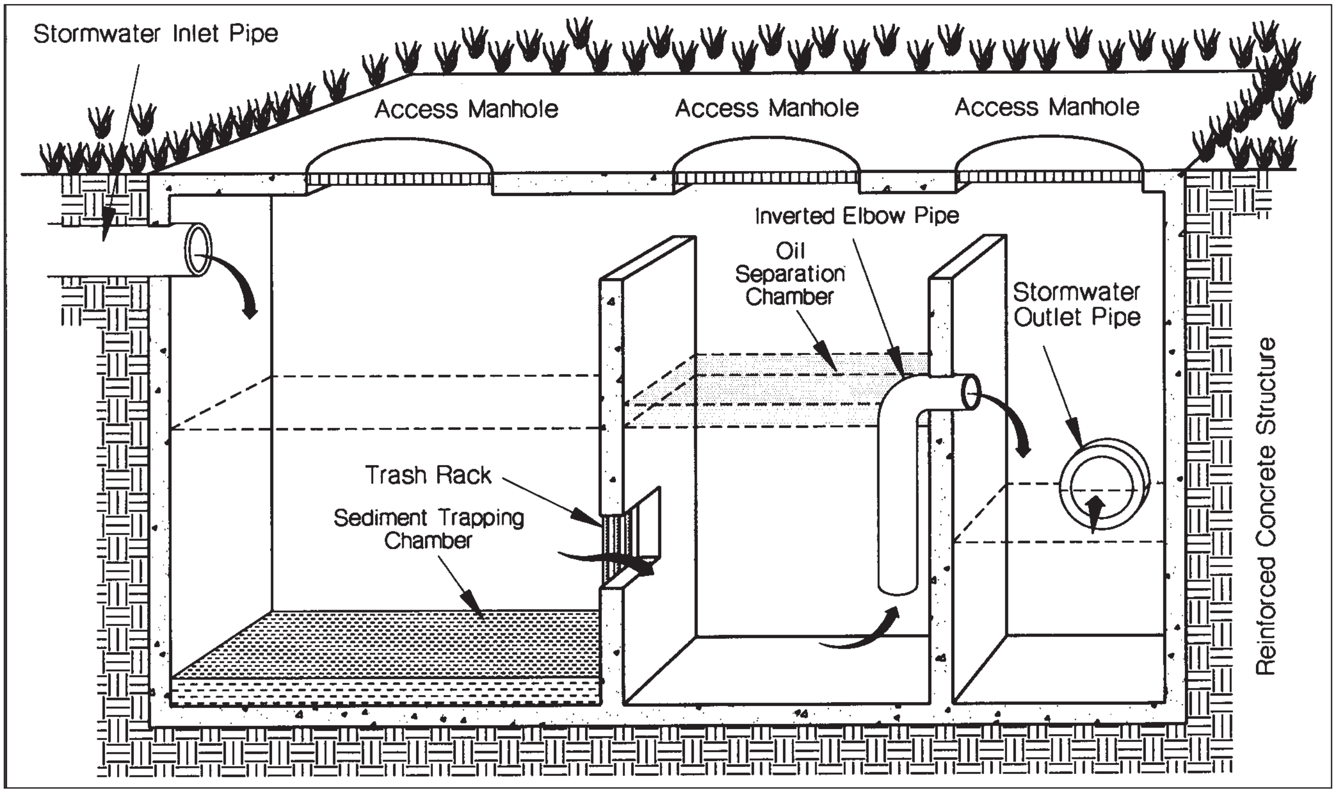


Figure 22.16 Schematic of a water quality inlet. (Courtesy of Engineers and Surveyors Institute and Northern Virginia Planning District Commission)

of 400 cubic feet of water per acre of contributing drainage area.

- Higher levels of pollutants can be removed by incorporating surface skimmers in the structure.
- The structure should be inspected regularly and cleaned at least twice per year to remove accumulated sediment, oil, grease, and other pollutants.

Sand Filter. There are a variety of different sand filters available for use depending on jurisdictional standards/preferences and the development application. They include the following.

Surface Sand Filter. This structural BMP is used to capture and treat a volume of stormwater runoff. This BMP is an excavated basin underlain by a sand filter bed with an underdrain system. Runoff collects in the basin and gradually infiltrates the sand bed. The underdrain then dewaters the sand bed, and flows are conveyed to a nearby swale or storm sewer. An overflow is used to divert higher volumes of flow. See Figure 22.17.

Subsurface Sand Filter. This structural BMP is used to capture and treat a volume of stormwater runoff. This structure consists of an underground concrete vault with distinct chambers designed for various levels of treatment. Flows enter and exit the structure through underground pipes, and flows from the filter are conveyed into a storm sewer or open channel. See Figure 22.18.

Perimeter Sand Filter. This structural BMP is used to capture and treat a volume of stormwater runoff. This BMP consists of an underground concrete vault with distinct chambers designed for various levels of treatment. Flows enter the structure through surface grates and exit the structure through underground pipes. Generally, one chamber collects sediments while the other chamber filters runoff. See Figure 22.19.

Organic Filter. This structural BMP is used to capture and treat a volume of stormwater runoff. This BMP is identical to the surface sand filter. However, the runoff storage zone is underlain by a 50/50 peat and sand mixture filter bed with an underdrain system. This filter is used in areas where maximum nutrient or trace metal removals are desired. The underdrain system then conveys flows to a swale or storm sewer.

Pocket Sand Filter. This structural BMP is used to capture and treat a volume of stormwater runoff. This BMP is similar to the surface sand filter, but it is smaller in surface area. The filter consists of a small excavated basin with a runoff storage zone underlain by a sand filter bed. For this BMP, the lower portion of the sand bed has a pea gravel “window” on the surface that allows runoff into the filter if the surface becomes clogged.

General Sand Filter Application Guidelines

- The filter is used to enhance stormwater quality.
- The filter is subject to clogging if moderate to high levels of silts and clays flow into the facility, and it must

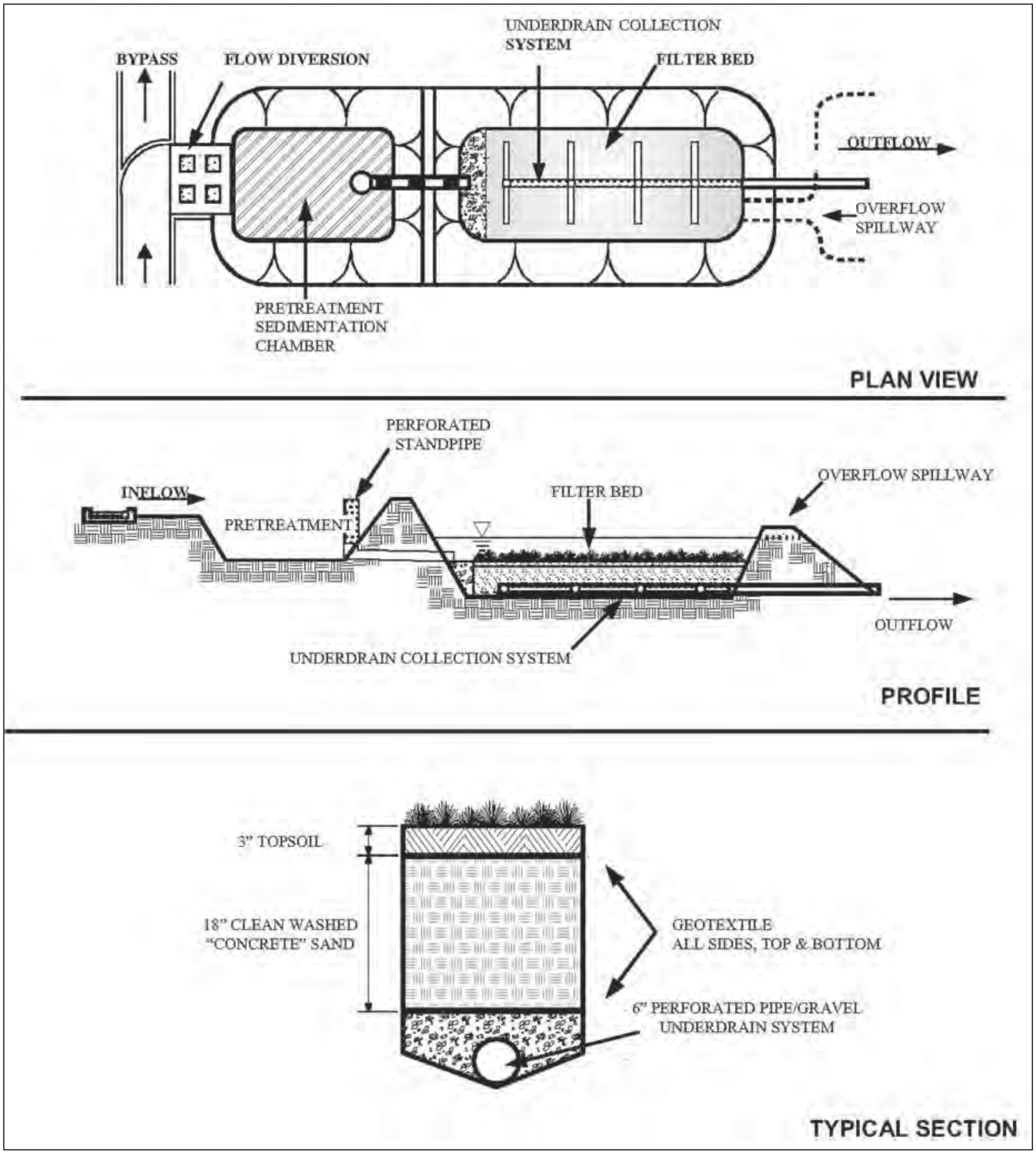


FIGURE 22.17 Plan, profile, and typical section of a surface sand filter. (MDE &CWP, 2000)

not be used while construction is occurring in the upstream catchment.

- Upstream grass channels, grass filter strips, or other BMPs can be used to help remove sediments and particulates before they enter the filter, reducing maintenance requirements.
- Filters are particularly useful at sites with limited space for water quality treatment or in high-value real estate areas. The subsurface and perimeter sand filter vault can be installed under parking lots and streets.
- Filters are most effective in treating runoff from small storms or early stages of larger storms.
- Filters are generally used in areas where sediment loads are low and there is no base flow.
- Subsurface sand filters are used to treat drainage areas of 5 acres or less.
- Filters are useful in watersheds where ground water quality is a concern or where low-permeability soils prevent infiltration.

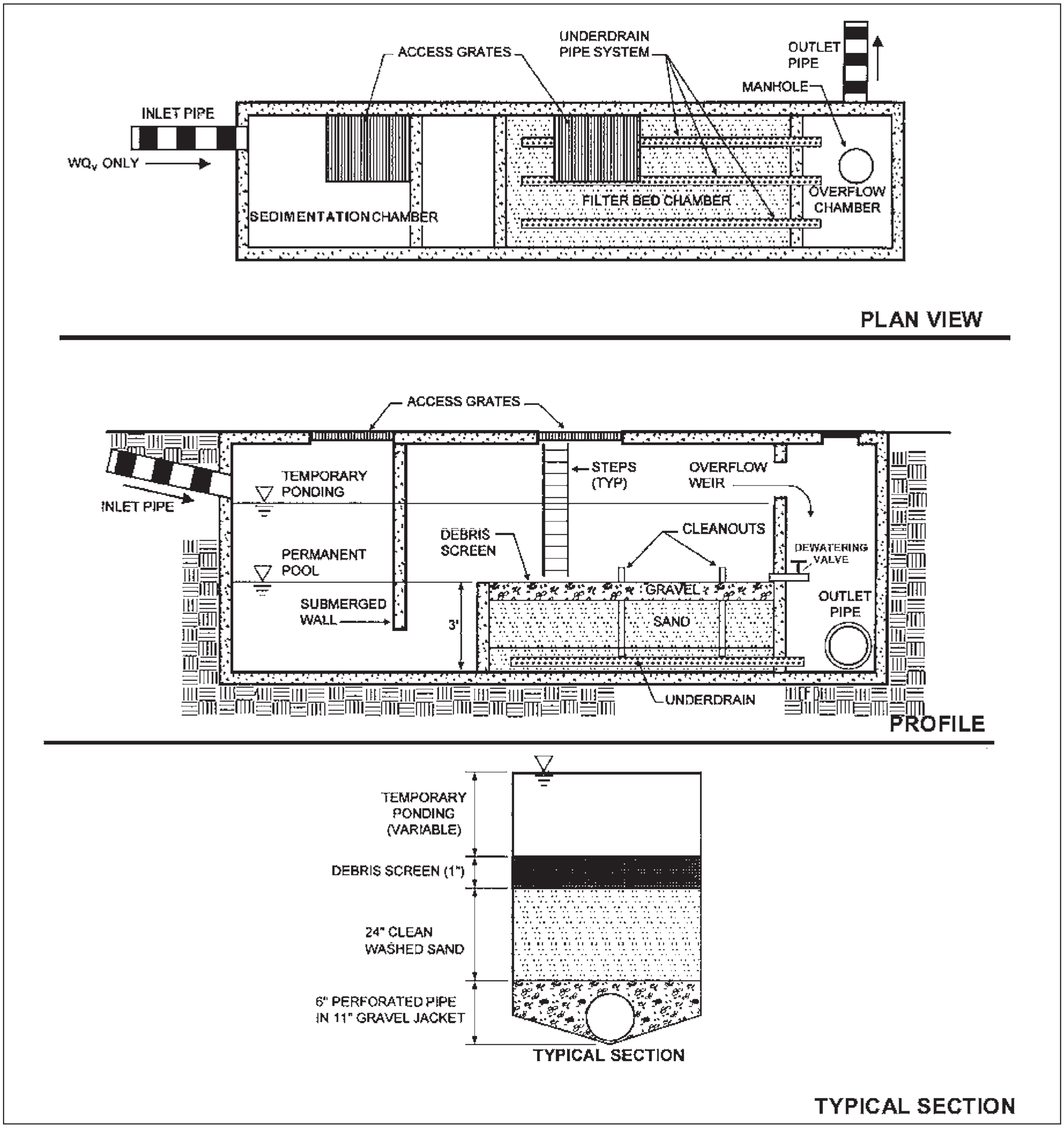


FIGURE 22.18 Plan, profile, and typical section of a subsurface sand filter. (MDE &CWP, 2000)

■ The upper chamber filters out finer materials and sediments. Flows percolate through a sand filter in the lower chamber and into an underdrain system.

■ A perimeter sand filter is also practical for small sites with flat terrain or a high water table.

Basic Design Criteria

■ Regular inspection and maintenance are necessary to remove surface sediment, trash, debris, and leaf litter.

■ A dense vegetative cover needs to be established over all contributing pervious areas before runoff can be conveyed to the filter.

■ Screens/grated inlets should be considered in design to keep debris out of filter chambers.

■ The filter bed typically has a depth of between 18 and 30 inches.

■ In certain cases, layers of sand must be replaced every three to five years.

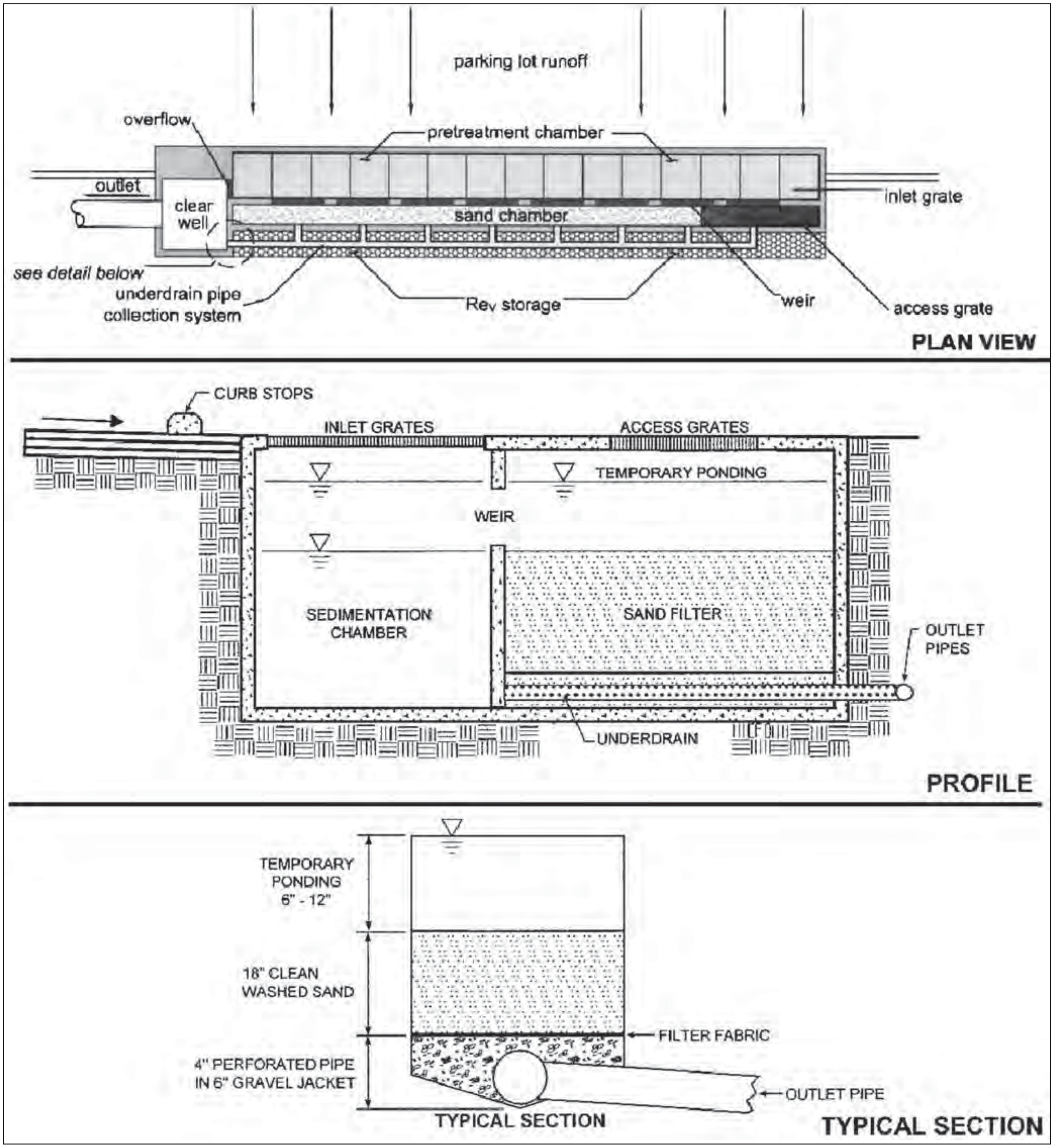


FIGURE 22.19 Plan, profile, and typical section of a perimeter sand filter. (MDE &CWP, 2000)

- Outlets and chambers must be cleaned/repaired when drawdown times in the filter exceed 36 hours.

IMPs and Low-Impact Development (LID) SWM Strategies

Low-impact development technology employs microscale and distributed management techniques, called *integrated management practices* (IMPs) to achieve desired postdevelopment hydrologic conditions. These IMPs are used to satisfy the storage volume requirements described in the "Principles of Hydrologic Routing" section of this chapter. IMPs are the preferred method of addressing stormwater management requirements because they are capable of maintaining the predevelopment runoff volume as well as integrating easily into the site design. The design goal is to locate IMPs at the source of runoff, ideally on level ground within individual lots of the development. Management practices that are suited to low-impact development include the following.

Infiltration Trench/Basin

Description. An infiltration trench/basin is a structural BMP used to capture and treat a volume of stormwater runoff. The trench consists of a stone-filled trench in which runoff is collected and percolated to the surrounding soils, while the basin consists of an excavated basin (sometimes rock-filled) in which runoff is collected and percolated to the surrounding soils. Grass channels, filter strips, or forebays can be used to reduce sediments entering the trench. Generally, the trench is 3 to 8 feet deep and filled with 1.5- to 2.5-inch-diameter clean stone or bank run gravel. The basin has a flat floor with an underdrain system. There is a diversion/overflow structure or weir for higher volumes of flow. See Figures 22.20 and 22.21.

Application Guidelines

- Both trench and basin can be used to enhance stormwater quality, reduce peak discharges, and recharge ground water.

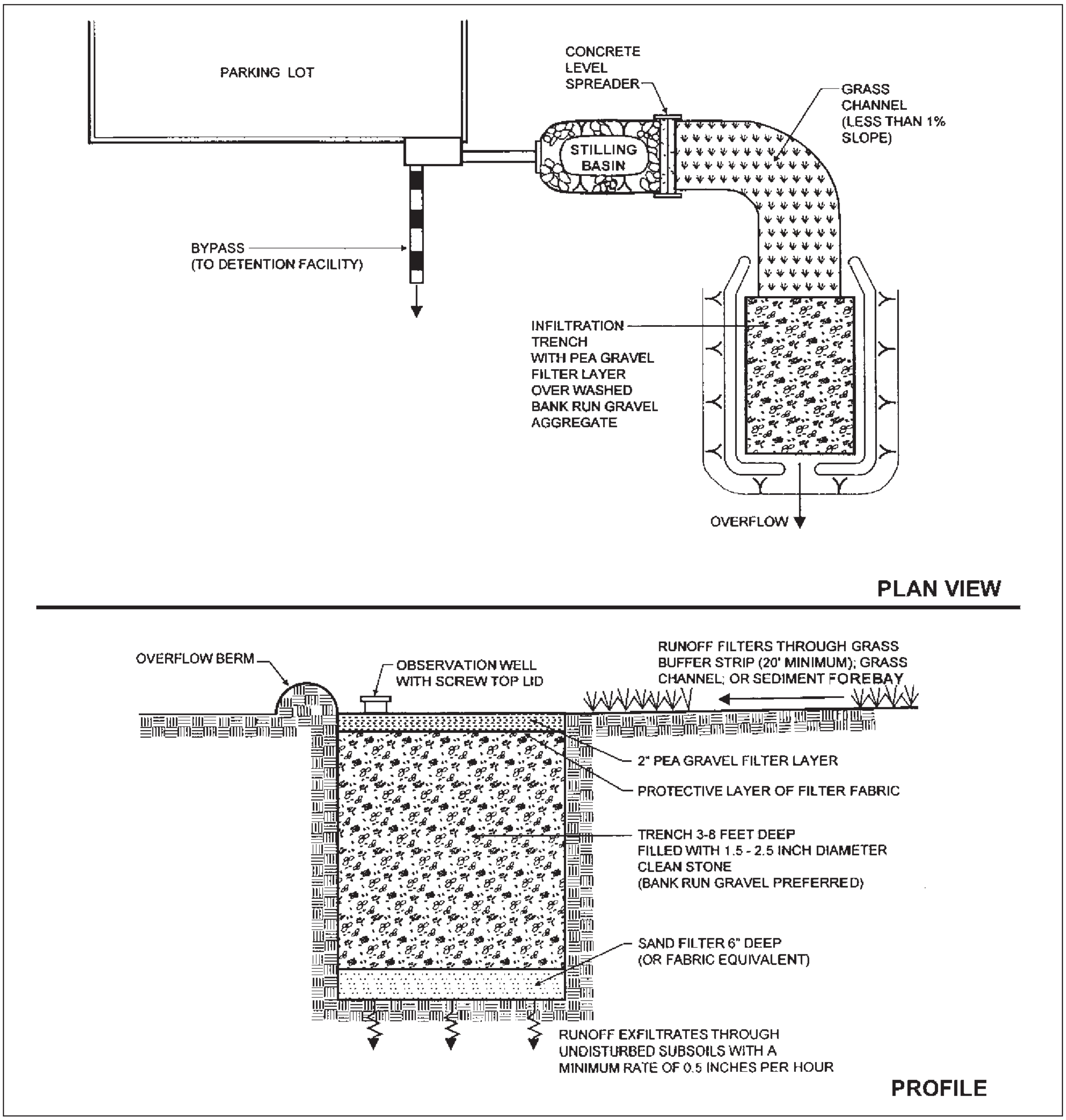


Figure 22.20 Plan and profile views of an infiltration trench. (MDE &CWP, 2000)

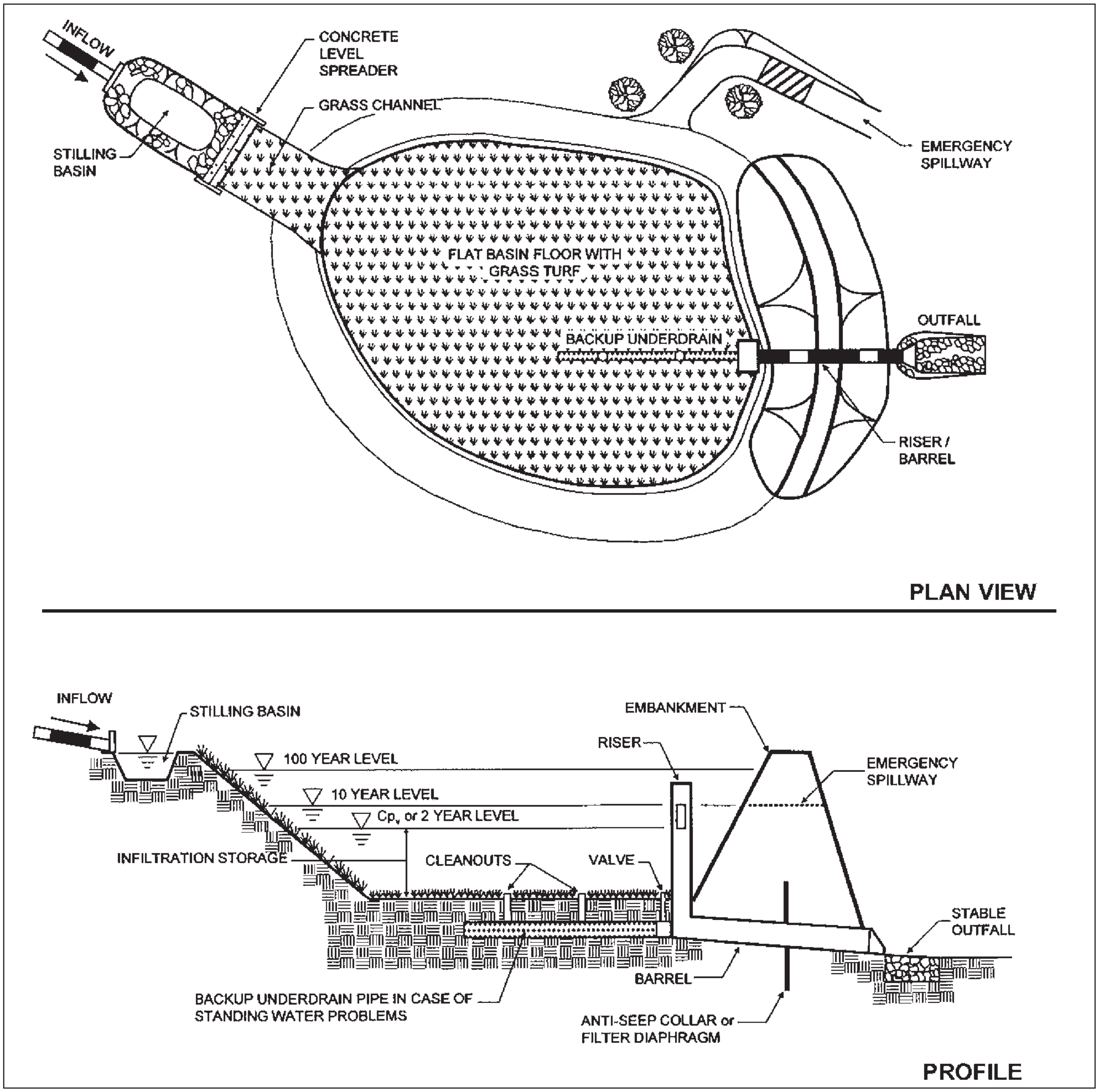


FIGURE 22.21 Plan and profile views of an infiltration basin. (MDE &CWP, 2000)

- Structures are prone to clogging by suspended solids and are best used in conjunction with other BMPs that are more effective in removing suspended solids.
- Neither should be used on or adjacent to steep slopes, and they are typically used for drainage areas less than 5 acres.
- Trenches should be used only in well-drained soils of Hydrologic Soil Groups A or B. However, they can be used in Hydrologic Soil Groups C and D soils if used for a very small drainage area, such as the backyard of a single-family residence.
- The bottom of both facilities should be 4 feet higher than the seasonal high-water table or bedrock.
- Trenches recharge surface runoff directly to ground water and should not be used in areas where there are concerns about contamination of ground water with dissolved pollutants.
- Neither should be installed in highly permeable sand or gravel seams that are directly connected to aquifers.
- Both can be connected to parking lot drains, roof downspouts, or inlet structures.
- Upstream stilling basins can be used to pretreat portions of the water quality volume.
- Basins should be used only with well-drained soils of Hydrologic Soil Groups A or B.

Basic Design Criteria

- Generally, these facilities are designed to infiltrate retained runoff within a 48-hour period.
- Accumulated sediments render these facilities ineffective, and regular inspections are needed. These sediments must be controlled to lengthen the effective life span.
- No vehicular traffic and minimal pedestrian traffic should be allowed over the trench.
- Facilities should be monitored to observe the time required for water to infiltrate the soil after a storm event.
- Periodic observations should also be made to monitor any decrease in performance.
- A dense vegetative cover needs to be established over all contributing pervious areas before runoff can be conveyed to the trench.
- Dewatering methods need to be designed in the event of a failure.
- The trench can be designed with a perforated drainpipe placed near the top of the trench. This allows the volume of stormwater in the trench (below the level of the drainpipe) to infiltrate the subsoil. Any stormwater in excess of this volume will then be carried in the drainpipe to the outlet.
- Overland relief must be provided so that runoff from very large storms does not cause unnecessary flooding or damage.

See Figure 22.22.

Bioretention

Description. This structural BMP is used to capture and treat a volume of stormwater runoff. The bioretention area is an excavated area filled with planting soil or a sand/planting soil mix. Runoff ponds in the depression on top of the bioretention area and percolates through the sand/soil later. Flows are then conveyed by an underdrain system connected to a storm sewer, open channel, or stream. See Figure 22.23.

Application Guidelines

- This structure can be used to enhance storm-water quality, reduce peak runoff, and recharge ground water.
- A bioretention facility can be used in residential and nonresidential development areas.
- The excavated area is lined with layers of filter fabric.

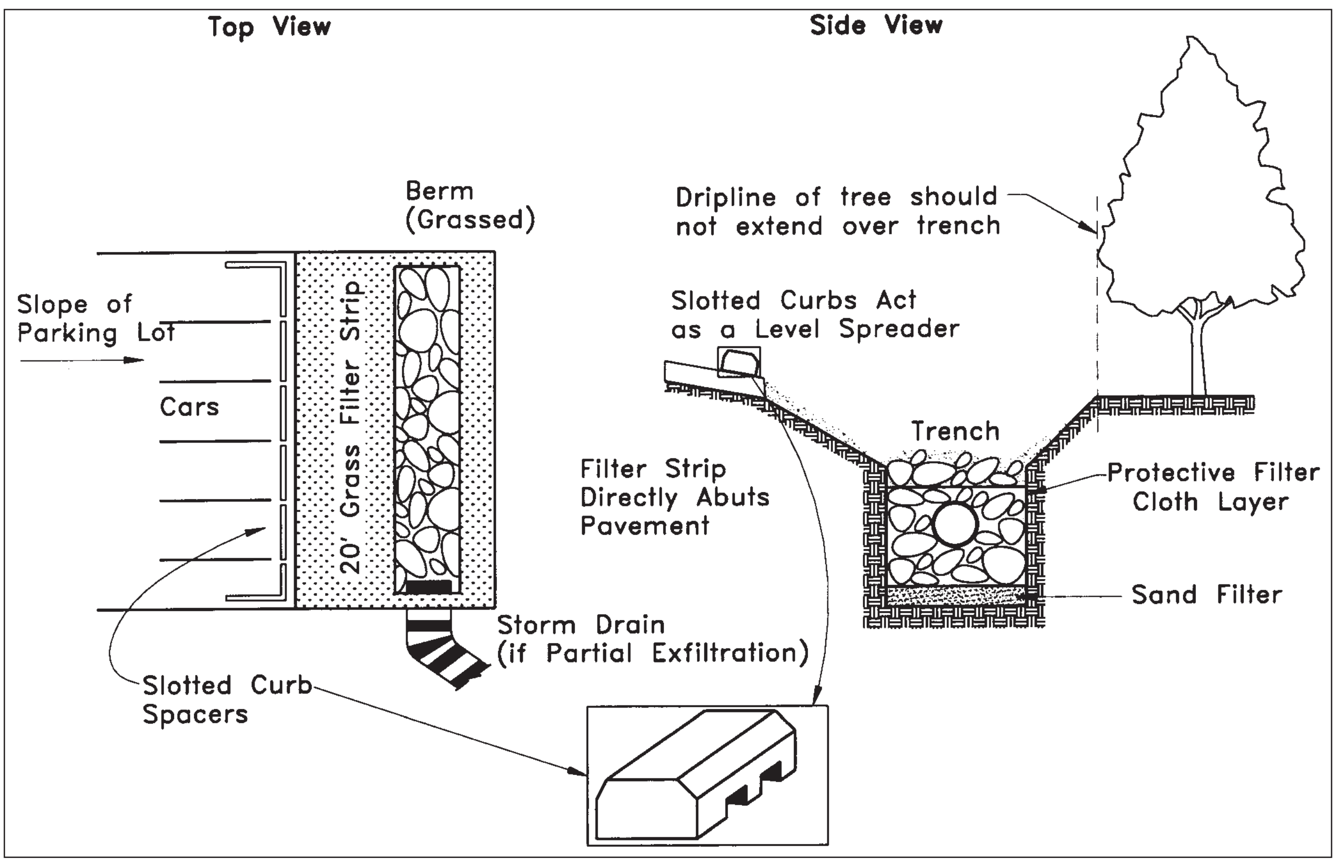


FIGURE 22.22 Plan and typical section of a parking lot perimeter trench. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

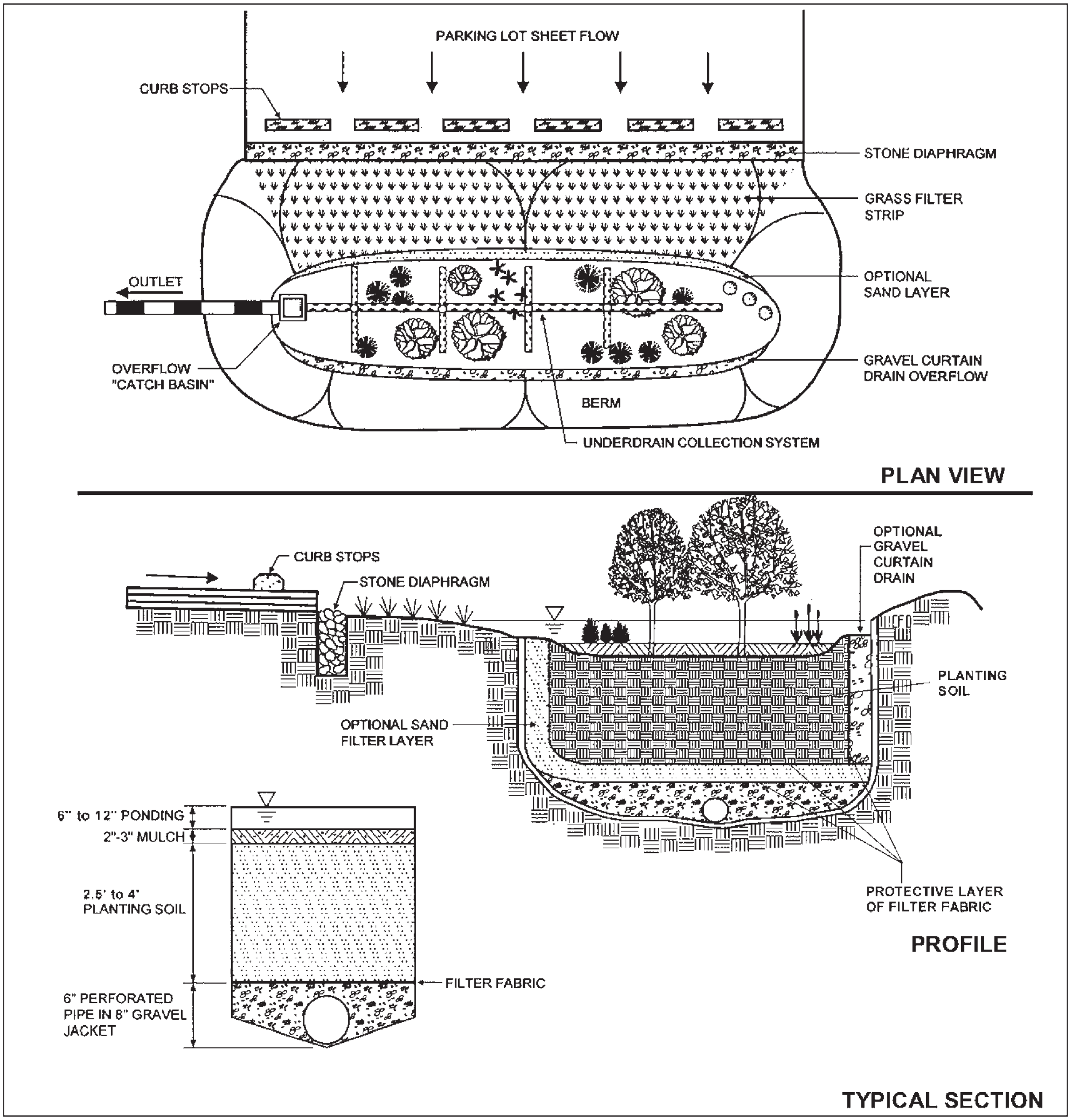


FIGURE 22.23 Plan and profile views of a bioretention facility. (MDE &CWP, 2000)

■ Bioretention facilities are efficient for removing a wide variety of pollutants including suspended solids and nutrients.

■ The structure can be offline, receiving runoff from overland flow or other structures in a traditional drainage system, or online, where structures are located in grass swales or other conveyance systems that have been modified to enhance pollutant removal.

■ Upstream grass channels or grass filter strips can be used to help protect the integrity of the facility.

■ Bioretention facilities are generally suited for drainage areas of 10 acres or less.

■ Runoff sources can be overland flow from impervious areas or discharges from drainage pipes.

■ Bioretention facilities are most effective if the retention area can be located as close as possible to the runoff source.

Basic Design Criteria

■ Generally, basins are designed to infiltrate retained runoff within a 40-hour period.

■ Regular inspection and maintenance are necessary to remove surface sediment, trash, debris, leaf litter, and dead or diseased plant material.

■ A dense vegetative cover needs to be established over all contributing pervious areas before runoff can be conveyed to the bioretention facility.

■ The planting soil typically has a depth of approximately 2.5 to 4 feet.

■ The top of the bioretention area is depressed to allow for 6 to 12 inches of stormwater ponding.

Dry/Wet Swales

Description. A dry/wet swales is a structural BMP used to filter pollutants as stormwater runoff moves through it. This BMP is constructed as an open-channel with grass or other wetland vegetation to provide conveyance and to filter pollutants. Other features such as check dams, pretreatment forebays, gravel pads, and riprap can be used to temporarily inhibit stormwater runoff and enhance treatment. See Figures 22.24 and 22.25.

Application Guidelines

■ This structure can be used to enhance stormwater quality and reduce peak runoff.

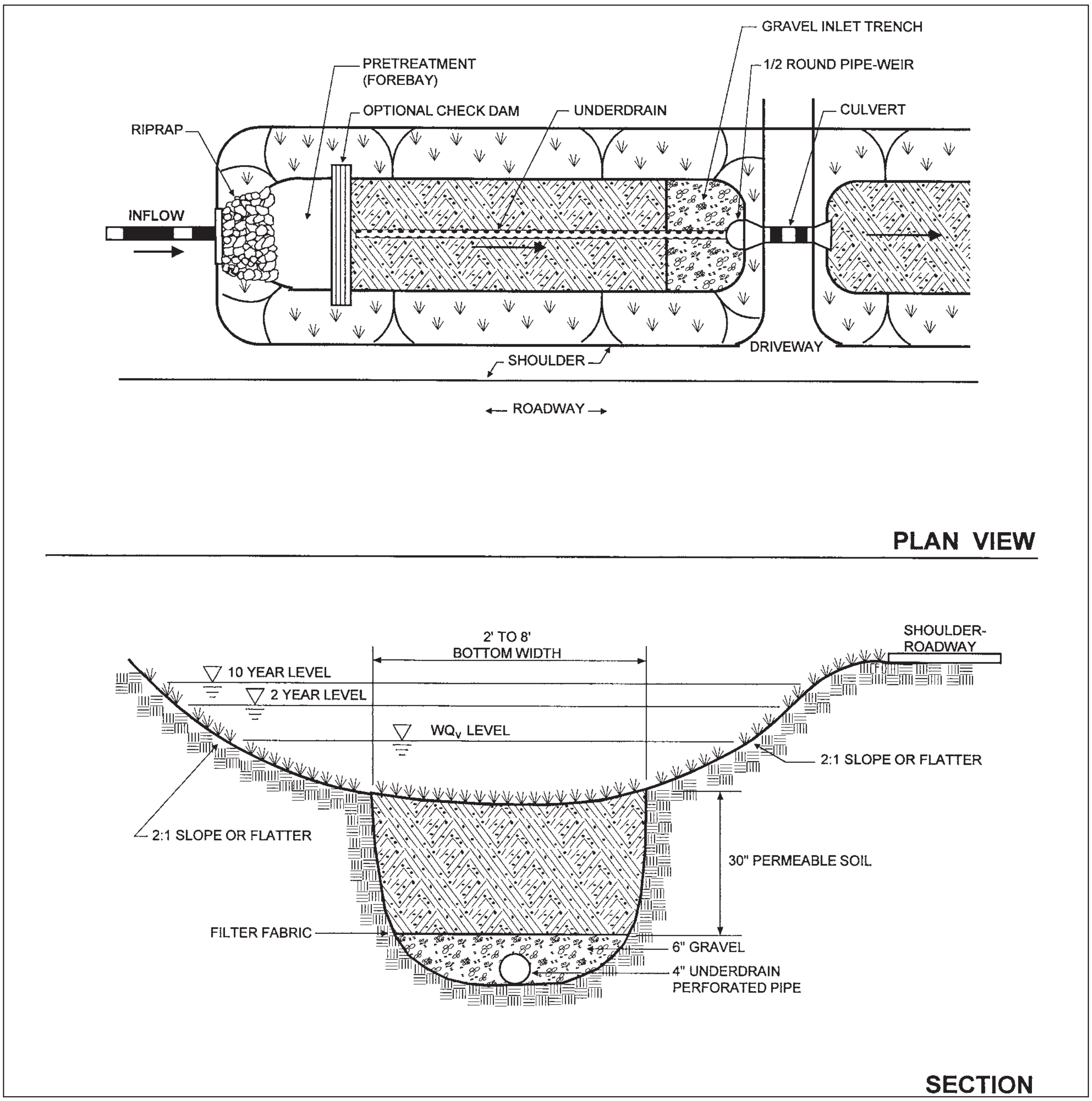


FIGURE 22.24 Plan and typical section of a dry swale. (MDE & CWP, 2000)

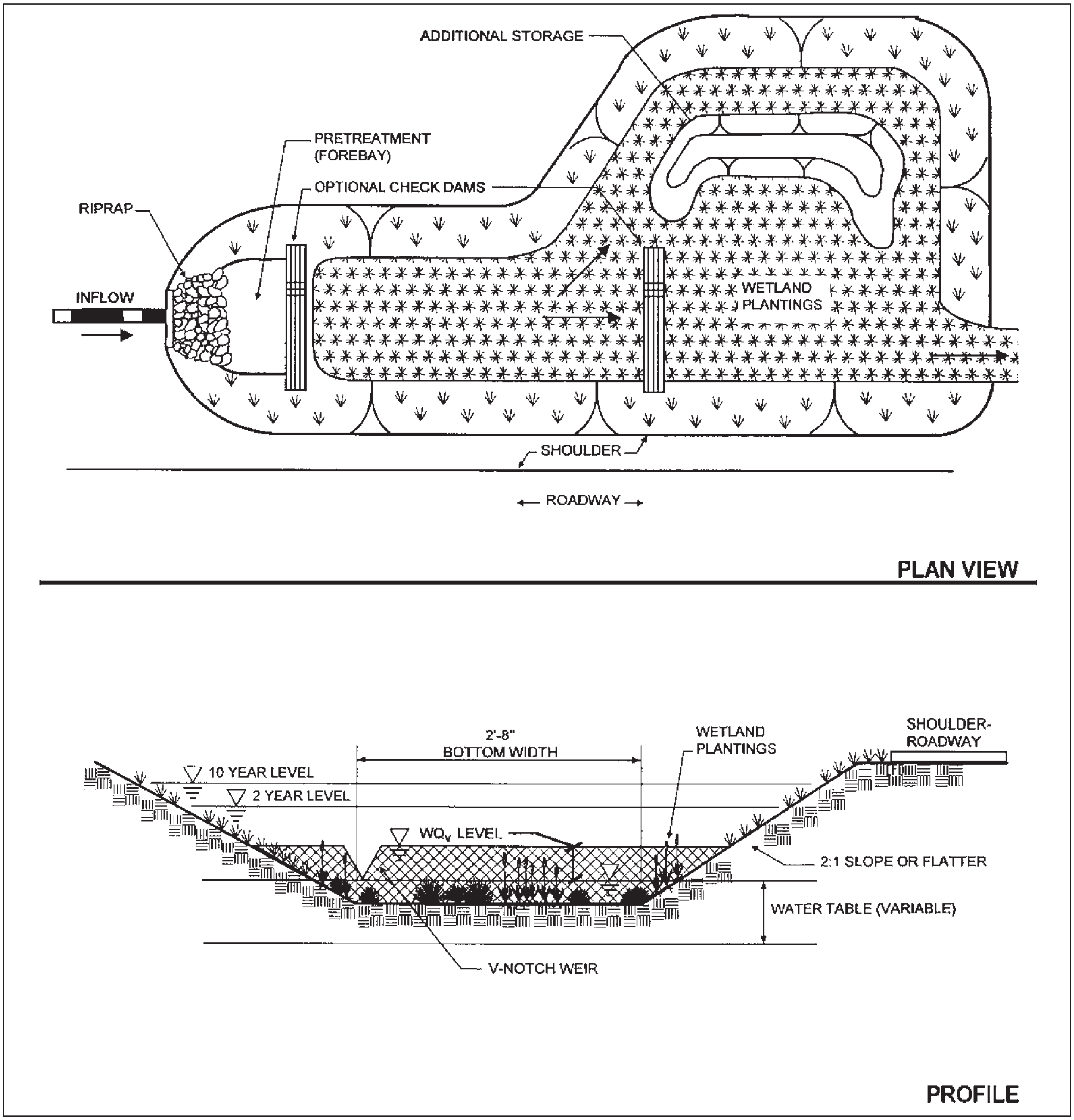


FIGURE 22.25 Plan and pofile views of a wet swale. (MDE & CWP, 2000)

- It is efficient for removing a wide variety of pollutants including suspended solids and nutrients.
- Swales work best in conjunction with other BMPs and can be used as an alternative to or enhancement of a conventional storm sewer.
- The excavated area is lined with layers of filter fabric around the permeable soil.
- Flows that infiltrate into the dry swale channel soil are conveyed by an underdrain system.
- Swales are used in low-density residential areas or for very small impervious areas.
- Runoff sources can be overland flow from impervious areas or discharges from drainage pipes.
- Swales are well suited for flat or rolling terrain.
- Swale depressions can be used in place of above-ground islands in large parking lots.
- Wet swales are ideal for treating highway runoff in flat-terrain areas.
- Wet swales can be used in residential areas if ponded water can be flushed frequently and wetland vegetation in the bottom of the channel can be established and maintained. Extended periods of standing

water may result in nuisance conditions and mosquito problems.

- Flows from wet swales are generally conveyed through a surface outlet structure to an open channel or stream, or directly into a storm sewer.
- If designed with check dams and/or depression storage, the swale can satisfy site runoff capture storage requirements for water quantity control.
- Swale depressions can be used in place of aboveground islands in large parking lots.

Basic Design Criteria

- Generally, swales are designed to temporarily store the water quality volume for a maximum of 48 hours.
- Regular inspection and maintenance are necessary to remove surface sediment, trash, debris, leaf litter, and dead or diseased plant material.
- A vegetative cover needs to be established as soon as possible to prevent erosion and scour, and it should be built early in the construction schedule before grading and paving increase runoff rates.
- The maximum ponding depth is generally no greater than 1.5 feet at the outlet.
- Longitudinal slope should be as flat as possible, to minimize velocities and enhance pollutant filtering.
- Frequent mowing is not required.

Porous Pavements

Description. This structural BMP consists of porous asphalt, concrete, lattice pavers, concrete blocks, or stones. The surface material is laid on a gravel subgrade and the surface voids are filled with sand or a sandy loam turf. Stormwater flows percolate through the pavement into the underlying soil. Using this BMP, streets, parking lots, sidewalks, and other impervious surfaces retain infiltration capacity. The three major types of porous pavement are open grid, concrete/asphalt, and gravel/grasspave. See Figures 22.26 and 22.27.

Application Guidelines

- Porous pavements are best used in areas of low traffic volumes and loads.
- An alternate approach is to use grass turf reinforced with plastic rings and filter fabric underlain by gravel.
- Porous pavements function to decrease the effective imperviousness of a project site.
- These are most often used in the construction of parking lots for office buildings and shopping centers. Other uses include traffic islands, emergency stopping areas, road shoulders, residential driveways, airport parking aprons, and maintenance roads.
- The structural and functional characteristics of the surfaces they replace are maintained.
- There is potential for high particulate pollutant removal.

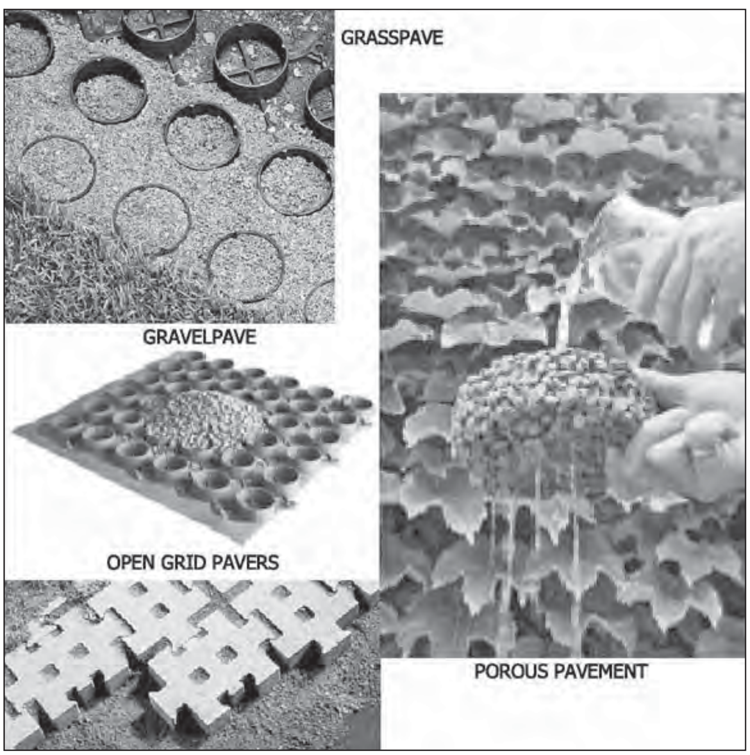


Figure 22.26 Some of the various porous pavement options—gravel pave, grass pave, open grid, and porous pave. (Photos courtesy of Invisible Structures and Pavestone)

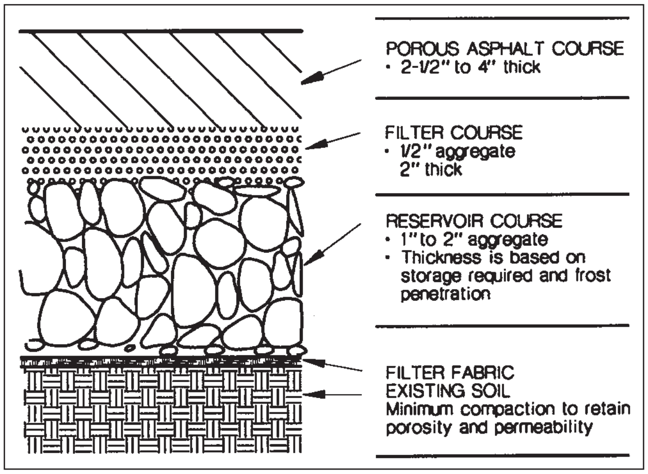


FIGURE 22.27 Schematic of typical porous pavement section.

- These can be used to reduce flooding by infiltrating or slowing down stormwater runoff.
- Lattice pavers, blocks, or stones can enhance site aesthetics.

Basic Design Criteria

- Initial pollutant removal rates are high but decrease as the porous materials become clogged. Careful attention to maintenance is necessary to reduce clogging. Maintenance should include vacuum sweeping and jet hosing.
- Suitable sites are generally limited to low traffic areas with a minimum soil infiltration capacity of 0.5 inches/hour.
- Porous pavements should not be used in areas of high contaminant loads such as gas stations or loading docks, and the proximity of the pavement to ground water needs to be considered.
- Pavement thickness should be sufficient to protect the subgrade.
- Quality base and subbase materials should be used to support the applied loads.
- An underdrain system can be used if subsoils cannot adequately infiltrate the expected flows.
- Adjacent unpaved areas should be stabilized to prevent sediment from washing into the porous pavement area.

Dry Wells

Description. This structural BMP is used to capture and treat a volume of stormwater runoff. This BMP provides stormwater storage prior to infiltration and may meet ground water recharge requirements. A dry well is very similar to an infiltration trench, with two important differences: it is much smaller and it is usually connected directly to a rooftop downspout. See Figure 22.28.

Application Guidelines

- A dry well infiltrates water through the stone medium into the underlying soils.
- Use of dry wells can reduce the amount of storage required in other downstream BMPs.
- Dry wells are smaller than infiltration trenches, typically treating about 500 square feet to as much as 1 acre of imperviousness.

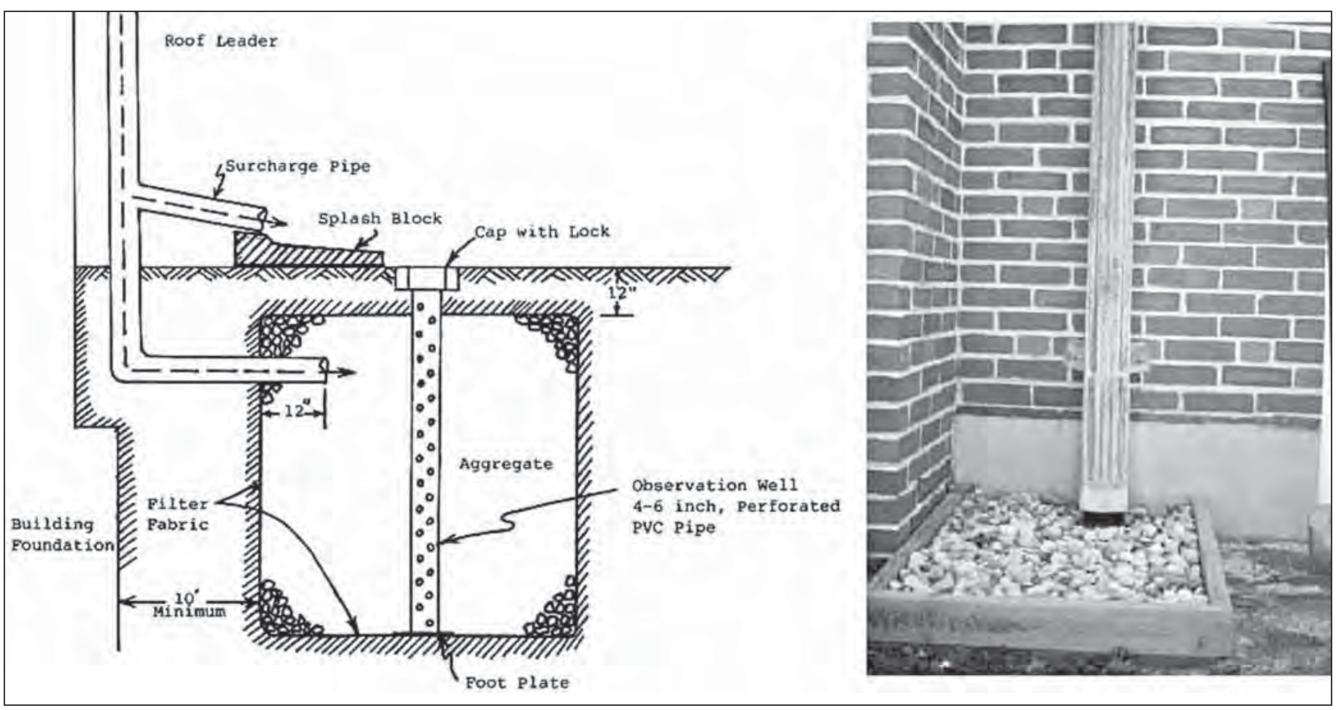


FIGURE 22.28 Dry well detail/picture. (MDE & CWP, 2000, and Maine DEP Conservation Practices for Homeowners Factsheet Series)

■ A dry well is typically considered a stormwater quantity control BMP; however, some jurisdictions allow water quality control credit for the pollutant removal attained through infiltration.

■ Common in residential settings, dry wells are often directly connected to downspouts.

■ Dry wells should be located at least 10 feet from the building foundation to prevent seepage into the basement/foundation.

■ Dry wells should also be located at least 100 feet from any drinking water well to prevent contamination.

■ Soil permeability must be at least 0.2 inches/hour, and for ground water recharge applications, a minimum soil permeability rate of 0.5 inches/hour is typically required.

■ Do not use dry wells in areas where there is high sediment loading (this can lead to rapid clogging of the well) or areas that have hazardous chemicals or other pollutants that can contaminate ground water.

Basic Design Criteria

■ The dimensions of the dry well are determined based on the design storm (usually 0.5 inch to 1 inch of rainfall or the one- or two-year storm) and the drawdown time (typically 48 to 72 hours), both of which vary depending on the jurisdiction.

■ Dry wells should be located at least 4 feet above the seasonal high ground water level.

■ The maximum depth of a dry well can be determined by using the following formula:

$$d_{max} = \frac{fT_s}{n} \tag{22.11}$$

where d_{max} = depth of dry well (inches), f = permeability rate (inches/hour), T_s = storage time (hours), n = porosity of stone (typically 0.40).

■ Once the well depth is determined based on Equation 22.11 and/or the ground water elevation, the area of the well is determined as follows:

$$A = \frac{V_s}{(nd + fTs)} \tag{22.12}$$

where A = area of dry well (feet), V_s = required storage volume based on design storm, and d = depth of the well as determined previously (feet),

■ Flows in excess of the design storm will bypass the dry well via a surcharge pipe.

■ Crushed stone size should be between 1½ and 3 inches.

■ Geotextile is typically placed at the interface of the soil and stone.

■ During construction, the subsoil (soil below the stone) should *not* be compacted.

■ Provide an observation well to monitor clogging.

■ Inspect the well after significant rainfall events and if there is standing water on top of the dry well or in the observation well for longer than 72 hours.

■ Clean/replace aggregate and filter fabric when clogged or every 3 to 5 years as part of routine maintenance.

Rain Barrels/Cisterns

Description. Primarily quantity control BMPs, rain barrels and cisterns are generally used to detain (or retain) small-frequency storms and hold water for on-site reuse applications. A small orifice or other manually operated outlet control (hose or nozzle) is used to control the outflow from the rain barrel or cistern. Secondary water quality benefits can be obtained, as runoff (typically from the rooftop) is screened at the inlet and, depending on the facility sizing, may be detained long enough for sedimentation to occur or, in large applications, be filtered. Common reuse applications include irrigation and graywater uses internal to the building/structure. See Figure 22.29.

Application Guidelines

■ Postdevelopment volume reduction is possible when reuse is employed.

■ The facilities are flexible and can provide detention or retention by adjusting the outlet control device—partially open to detain or closed to retain, for a given storm.

■ Rain barrels are common in residential applications, as they tend to be the smaller of the two similar facilities, with a minimum size of approximately 55 gallons.

■ Cisterns are common in nonresidential and large-scale residential applications; they may be above or below ground and range in size and material from fabricated or precast tanks similar to rain barrels to cast-in-place vaults of nearly any size.

■ They are useful in rural, suburban, and urban applications and are relatively space conscious in that they are generally small enough to be screened in residential applications or buried or included in structured parking areas in nonresidential or condo-type applications.

■ Facilities may be placed in series to increase storage volume.

■ Inlet and outlet conditions should be carefully considered to minimize insect attraction and contamination while facilitating overflow or bypass.

■ Collected rainwater in barrels/cisterns is not potable and should be used only for landscaping or other graywater applications.

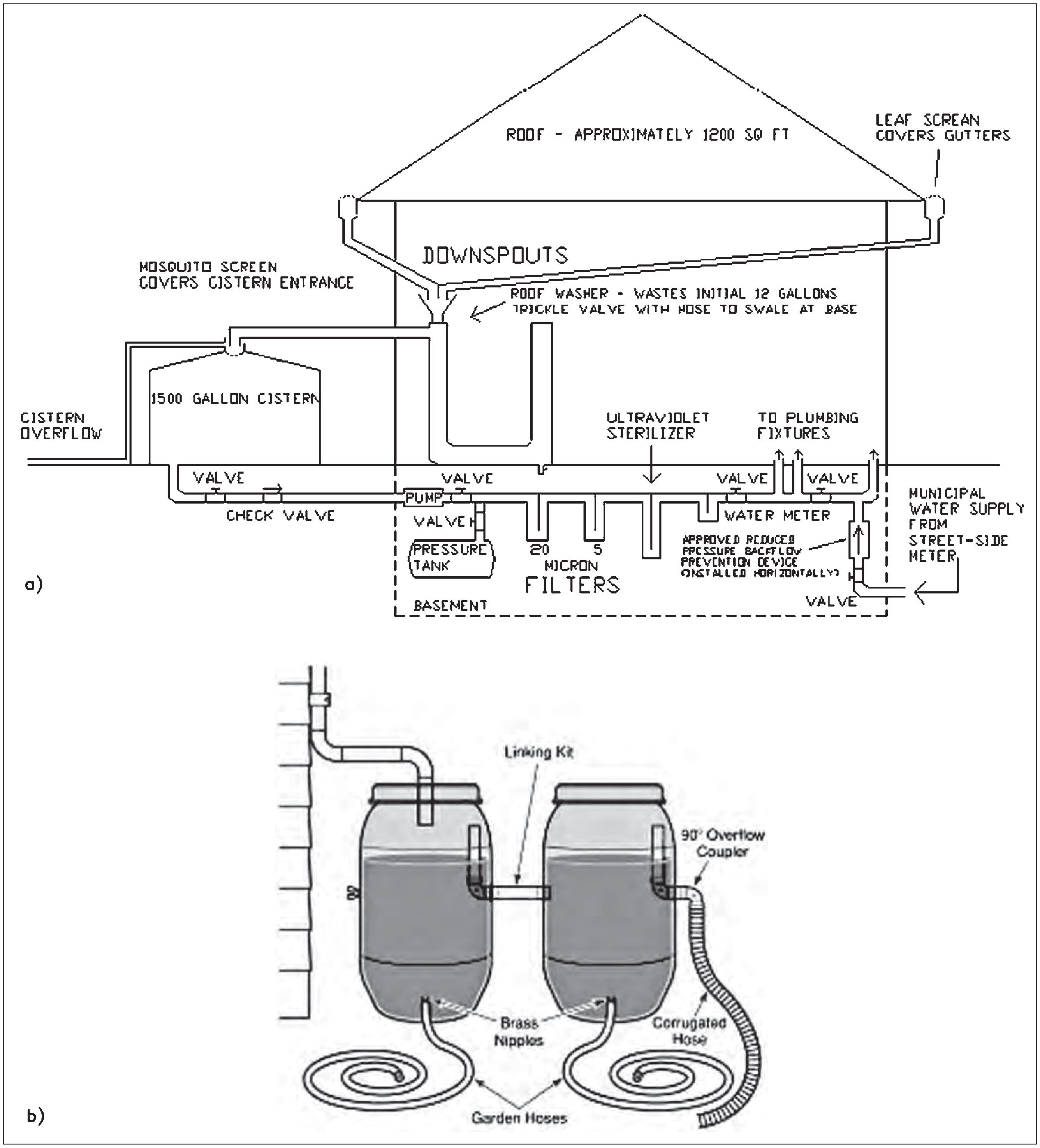


FIGURE 22.29 (*a*) Schematic section of a functioning cistern (Experiments in Sustainable Urban Living); (*b*) detail of a typical rain barrel installation (Composters.com, a subsidiary of the Green Culture)

Basic Design Criteria

- Determine the volume of rooftop runoff available:

$$V = A \times R \times E \times 7.48 \qquad (22.13)$$

where A is the rooftop area (square feet), R is the rainfall (feet), E is the efficiency of the system (usually estimated at 90 percent), and 7.48 is the conversion from gallons to cubic feet.

- Determine the allowable drawdown time, typically in the range of 24 to 48 hours, but this varies depending on climate, average rainfall, and the intended reuse application.

■ Size the outlet control device based on the drawdown time and detention volume.

■ Provide/design pumps if a gravity-based discharge system is not possible.

■ Account for overflow from larger storms with an appropriate bypass system.

■ Maintenance is required—a low-flow or dewatering spigot is required, and sediment levels should be checked periodically and removed to allow for proper functioning.

Conventional (Traditional) BMPs

The conventional BMPs listed here address the requirements of local jurisdictions for quality control by extended detention of the first flush of runoff. This extended detention time is intended to capture sediment and allow the pollutants attached to the sediment sufficient time to settle out of the water. These facilities can be enhanced by the inclusion of sediment forebays and micropools to increase their effectiveness.

Extended Detention (Dry) Pond with Micropool

Description. This structural BMP is used to capture and treat a specific volume of stormwater runoff. Because of a

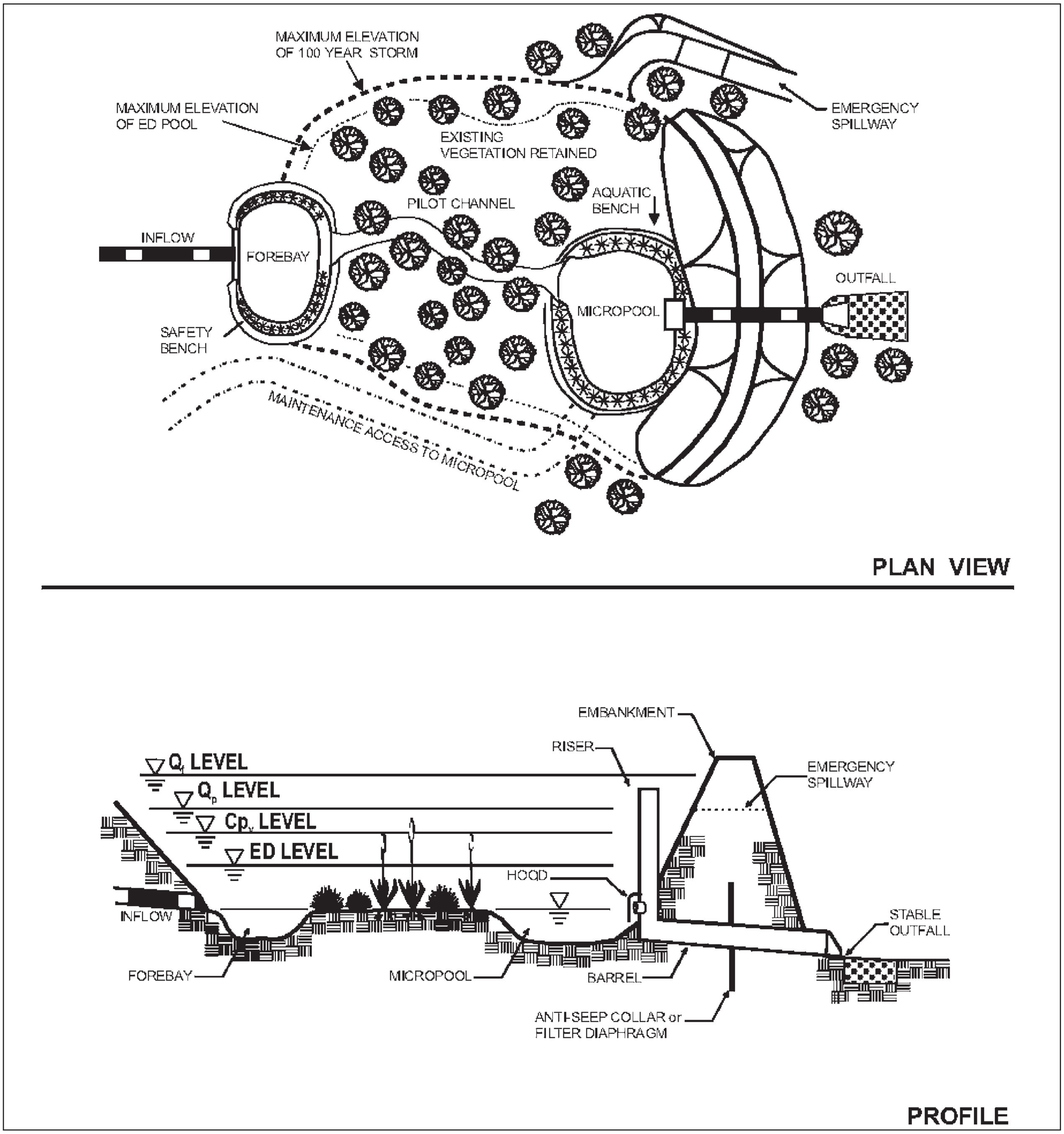


FIGURE 22.30 Plan and profile of an extended detention stormwater management pond. (MDE & CWP, 2000)

smaller outlet, the pond releases stored flows over a period of a few days and drains totally dry sometime after the storm ends. The pond is considered dry, although the formation of small wetland marshes or shallow pools in the bottom can enhance the effectiveness of the pond. See Figure 22.30.

Application Guidelines

- The pond can be used to enhance stormwater quality and reduce peak discharges.
- This BMP is most applicable in residential, commercial, and industrial areas.
- If constructed early in the development of a particular site, the pond becomes an effective means of trapping sediment from construction activities.
- Ponds can be retrofitted into existing flood control facilities.
- Ponds are used to improve the quality of urban runoff.
- Ponds are used for regional and/or follow-up water quality treatment, but they are also effective as on-site BMPs.
- Ponds also work well in conjunction with other BMPs used to control upstream and downstream sediments.
- Ponds can attenuate peak stormwater discharges and are used for water quality treatment.
- Pond size can be reduced if a pond is effectively combined with other water quality BMPs.
- Ponds can also be used for recreation and open space and, in some cases, wildlife habitat if wetlands or shallow pools are incorporated into the design.

Basic Design Criteria

- If possible, the pond should be incorporated into the existing facility or flood control basin.
- Consider other urban uses such as recreation, open space, and/or wildlife habitat.
- Generally, a minimum drain time of 40 hours is recommended to allow finer particulates found in urban stormwater runoff to settle.
- Generally, land required is approximately 0.5 to 2.0 percent of the tributary development area.
- Account for ground water elevations in the design and construction of the basin.
- Review regulatory requirements for dam embankments and storage volumes if minimum dam heights and volumes are exceeded.

Wet Pond

Description. This structural BMP is used to capture and treat a specific volume of stormwater runoff. This structure has a permanent pool, and runoff from each rain event is detained and treated in the pond until it is displaced by runoff from the next storm. The permanent pool enhances the effectiveness of the pond by promoting biological uptake. See Figures 22.31 and 22.32.

Application Guidelines

- A wet pond can be used to enhance stormwater quality and reduce peak discharges.
- It is most applicable in residential, commercial, and industrial areas.
- If constructed early in the development of a particular site, the pond becomes an effective means of trapping sediment from construction activities.
- The pond can be retrofitted into existing flood control facilities.
- Ponds are used to improve the quality of urban runoff.
- Basins are used for regional and/or follow-up water quality treatment but are also effective as on-site BMPs.
- Ponds also work well in conjunction with other BMPs used to control upstream and downstream sediments.
- Basins can be effective if they are combined with BMPs that attenuate peak stormwater discharges or reduce runoff volumes. If needed, flood routing detention volume can be designed and captured by the pond, above the volume used for water quality treatment.
- Pond size can be reduced if effectively combined with other BMPs.
- Basins can also be used for recreation and open space and, in some cases, wildlife habitat if wetlands or shallow pools are incorporated into the design.

Basic Design Criteria

- Generally, water quality flows require a minimum drain time of 40 hours to allow finer particulates found in urban stormwater runoff to settle.

FIGURE 22.31 Photograph of the Farrcroft Wet Pond that serves as a BMP facility as well as a community amenity.

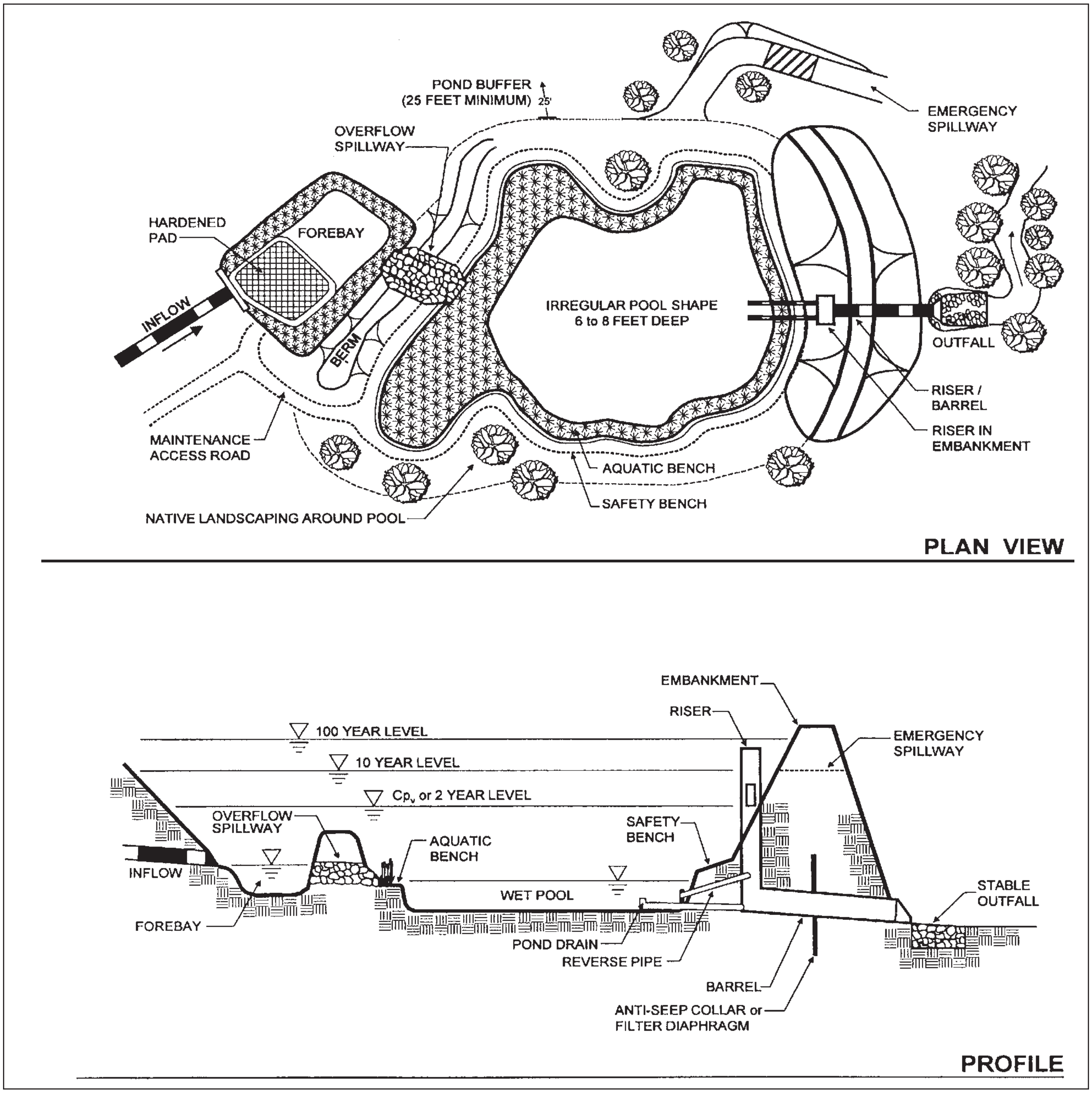


FIGURE 22.32 Plan and profile views of a "wet" stormwater management pond. (MDE & CWP, 2000)

- If possible, the pond should be incorporated into the existing facility or flood control basin.
- Consider other urban uses such as recreation, open space, and/or wildlife habitat.
- Generally, land required is approximately 0.5 to 2.0 percent of the tributary development area.
- Account for ground water elevations in the design and construction of the basin.
- Review regulatory requirements for dam embankments and storage volumes if the minimum dam heights and volumes are exceeded.

Figure 22.33 relates the expected long-term efficiency of pollutant removal as compared to the volume of the retention basin (V_B/V_R ratio). As Figure 22.33 indicates, the larger the V_B/V_R ratio—that is, the larger the basin size—the greater the efficiency that can be expected. However, Figure 22.33 also illustrates that after a certain point only a small increase in efficiency can be expected for a large increase in basin volume. See also Figure 22.34.

Pond shape is important in that it is desirable to provide the maximum possible distance between the inlet(s) and the outlet, provided that the incoming water displaces water already in the pond.

The recommended average depth of the pond is between 3 and 6 feet. Shallower ponds are more efficient, since set-

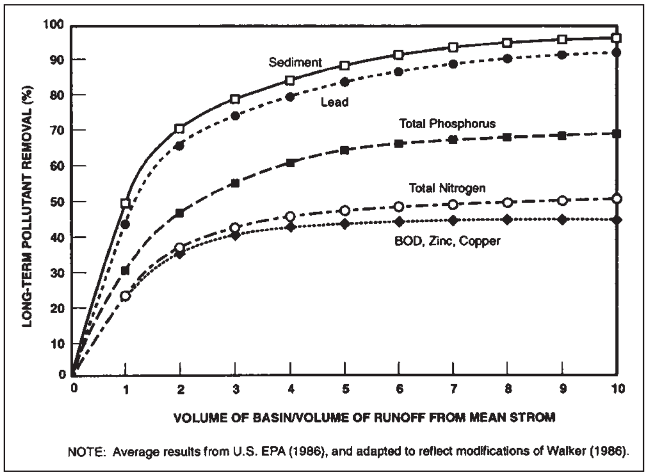


FIGURE 22.33 Estimated removal of selected urban pollutants as a function of permanent pool size.

tling is the primary removal mechanism, and removal is considered accomplished when the particles reach the pond bottom. However, a very shallow pond causes resuspension of settled particles by wave action and promotes vegetation throughout the entire pond. A very deep pond could become thermally stratified, which can result in anoxic conditions and possible subsequent resuspension of pollutants in the lower layers.

Shallow Wetland

Description. A structural BMP used to capture and treat a specific volume of stormwater runoff. This structure is similar to a stormwater pond. However, wetland vegetation is added to the bottom of the pond to enhance the pollutant removal capability of the structure. A perennial base flow is needed to promote wetland vegetation, and water quality treatment is provided in the shallow pool. See Figure 22.35.

Application Guidelines

- A wetland can be used to reduce peak discharges.
- A wetland can be used as a follow-up structural BMP or as a stand-alone facility.
- Small existing wetlands can be enlarged and incorporated into a constructed wetland (which requires state and federal permits).
- A wetland requires an area sufficiently large for impounding stormwater in shallow basins.

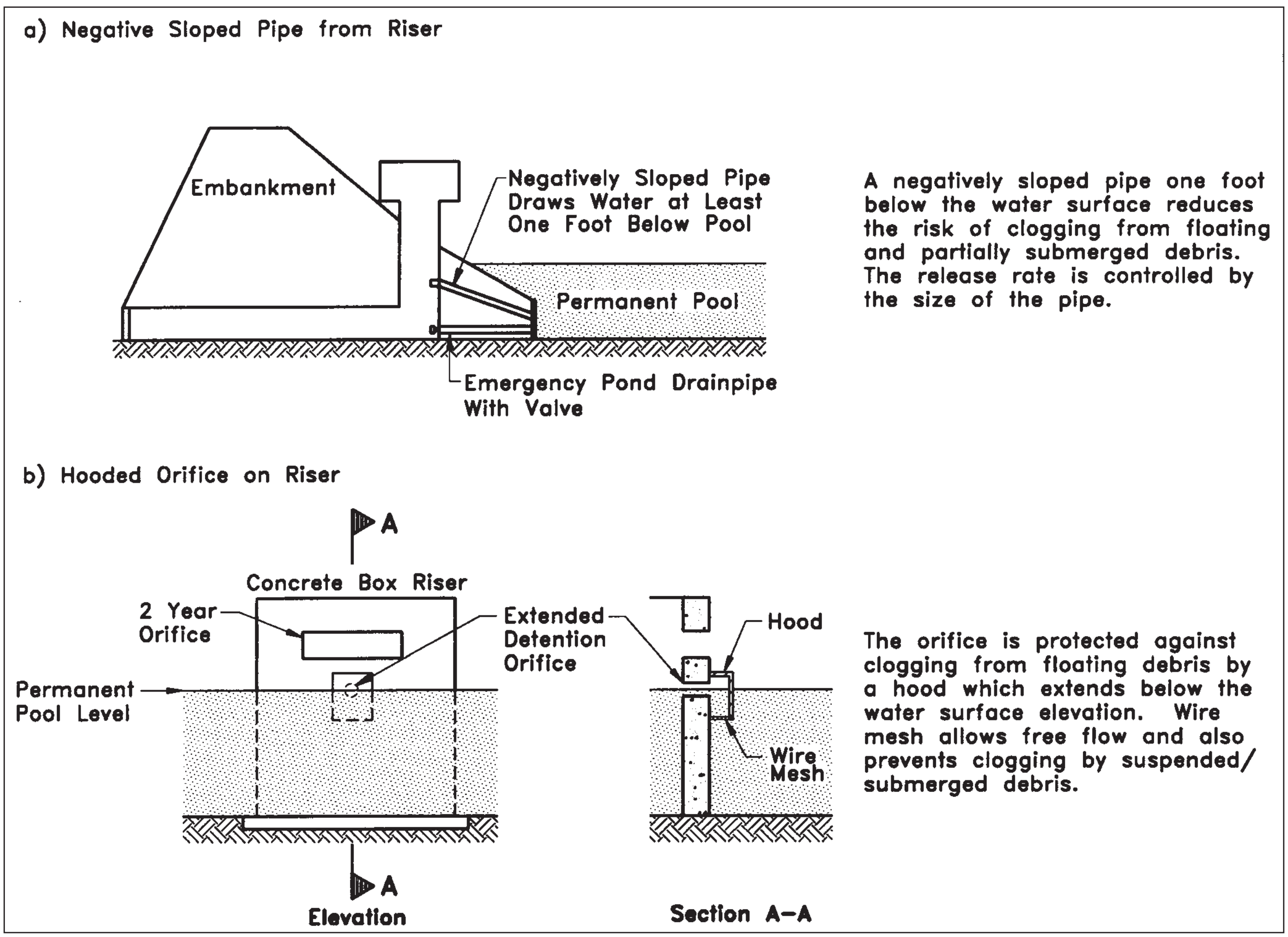


FIGURE 22.34 Design techniques to minimize the risk of clogging while providing extended detention time in stormwater management ponds. (Courtesy of Schueler, Thomas R. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs.* Washington, DC: Metropolitan Washington Council of Governments, 777 No. Capital St. NE, Suite 300, Washington, DC 20002-4226, 202/962-3256)

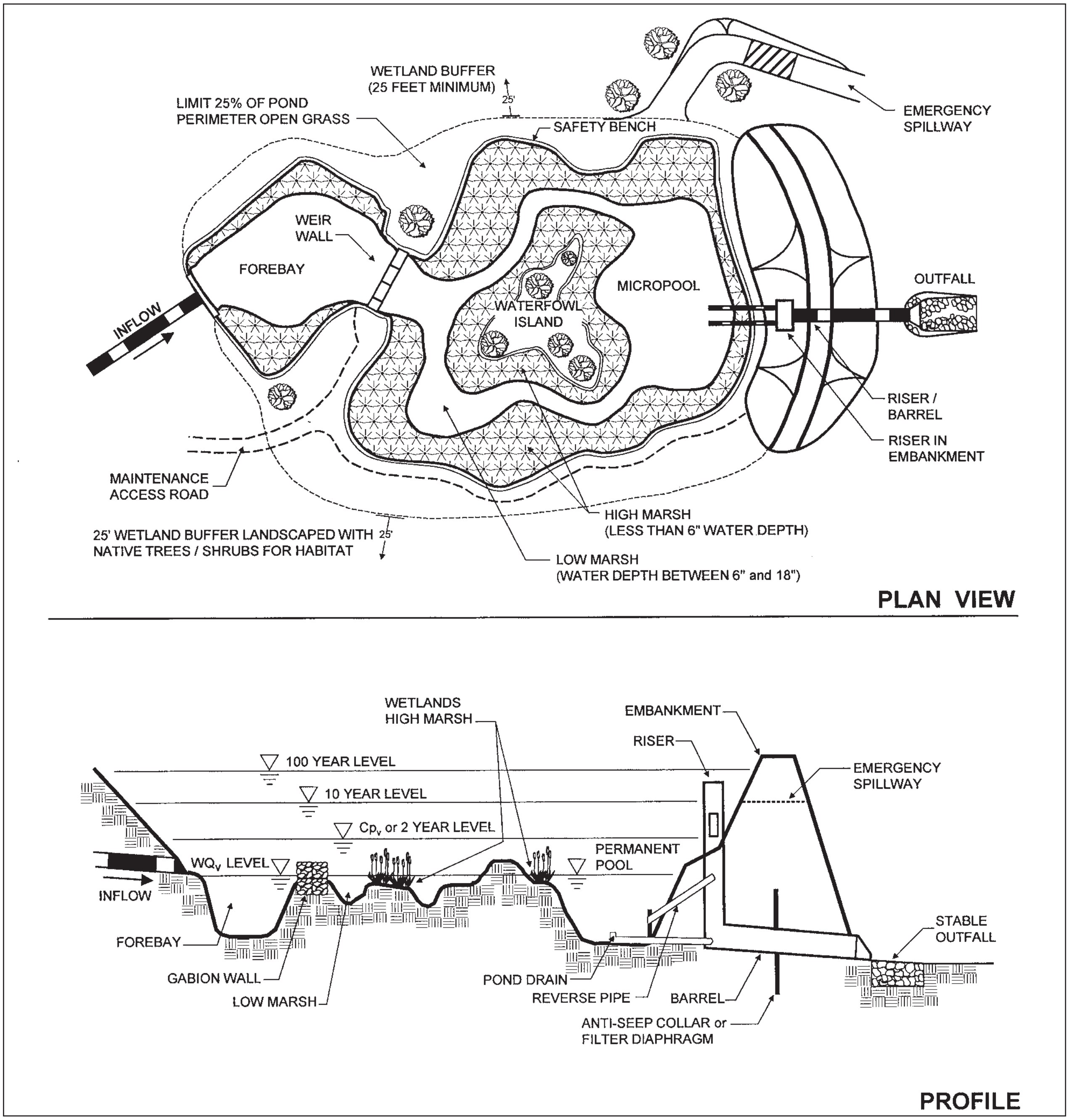


FIGURE 22.35 Plan and profile views of a shallow wetland stormwater management facility. (MDE & CWP, 2000)

- Wetland cells can be arranged in a series of terraces.
- If needed, flood storage can be provided above the volume used for water quality treatment.
- Wetlands can provide effective follow-up treatment to on-site and other basin BMPs.
- State and federal regulations protecting natural wetlands recognize the classification of wetlands constructed for water quality treatment.
- Constructed wetlands are generally not allowed on receiving waters and cannot be used to mitigate the loss of natural wetlands.
- The advantage is in aesthetics and the creation of wildlife habitat; the disadvantage is the need for continuous base flow to maintain wetland growth.

Basic Design Criteria

- Generally, a minimum drain time of 24 hours is recommended.
- Wetlands constructed outside of the Waters of the United States and explicitly designed for stormwater management, are not subject to the provisions of the Clean Water Act (Sections 401 and 404). When abandoned, they may be regulated as natural wetlands.

- Consider other urban uses such as recreation, open space, and/or wildlife habitat.
- Loamy soils are required in the wetland bottom to sustain plant growth.
- Perennial base flow is needed and is determined through a water budget analysis.
- Exfiltration through the pond bottom is not reliable because of low-permeability soils and/or high ground water elevations.
- Review regulatory requirements for dam embankments and storage volumes if minimum dam heights and volumes are exceeded.

DETENTION POND DESIGN EXAMPLE

A 50-acre parcel covered with brush and woods is projected for development into 40 acres of 1-acre residential lots and 10 acres of commercial/retail development. The site is located in southeastern Virginia. The HSG is type B (fair condition). Using SCS hydrologic methods, determine a preliminary size for the detention pond and the spillway to detain the 10-year/24-hour design storm and to pass the 100-year/24-hour storm without overtopping the embankment. Allowable discharge rate from the spillway for the 10-year storm cannot exceed the predevelopment peak runoff. Site constraints dictate that the maximum allowable height of the embankment is 10 feet. A schematic diagram of the project site is shown in Figure 22.36.

1. The time of concentration and CN are needed for predevelopment conditions, to compute the predevelopment peak runoff rate.
   a. From Figure 19.3, the 2-year/24-hour rainfall depth is 4 inches, and from Table 19.12, n = 0.4. From topographic maps of the site, the average ground slope for the first 300-foot flow path of sheet flow runoff (shown A to B in Figure 22.36) is 0.035 foot/foot. From Equation 19.19, the travel time is:

$$T_t = \frac{(0.007)[(0.4)(300)]^{0.8}}{(4)^{1/2}(0.035)^{0.4}} = 0.51 \text{ hours} \qquad (22.14)$$

   b. The travel time for 700 feet of shallow concentrated flow (B to C on Figure 22.36) over an average ground slope of 0.02 foot/foot (from a topographic map of the site) from Equation 19.20 is:

$$V = (16.1345)(0.02)^{1/2} = 2.3 \text{ fps} \qquad (22.15)$$

$$T_t = \frac{700}{(3600)(2.3)} = 0.09 \text{ hours}$$

   c. From field reconnaissance, the 1000-foot length of the stream is rectangular in shape with average dimensions; the bottom width = 4 feet and the depth = 2 feet. Manning's n ≈ 0.03 and S = 0.004 foot/foot. Using Equation 19.21,

$$V = \frac{1.49}{0.03}\left(\frac{(2)\,(4)}{2(2)+4}\right)^{0.67}(0.004)^{1/2} = 3.1 \text{ fps} \qquad (22.16)$$

$$T_t = \frac{1000}{(3600)(3.1)} = 0.09 \text{ hours}$$

   d. The predevelopment t_c = (0.51) + (0.09) + (0.09) = 0.69 hours.
   e. The CN = 65 is obtained from Table 19.11 for the woods-grass category under HSG B (fair condition). Using Equation 19.17,

$$S = \frac{1000}{65} - 10 = 5.4 \qquad (22.17)$$

   f. From Figure 19.5, the 10-year/24-hour rainfall is 6 inches. Substituting for P and S in Equation 19.18, the depth of runoff is:

$$Q = \frac{[6-(0.2)(5.4)]^2}{6+(0.8)(5.4)} = 2.3 \text{ inches} \qquad (22.18)$$

   g. Since $I_a = 0.2S$, $I_a = 1.08$ and $I_a/P = 1.08/6 = 0.18$. Use Figure 19.22 (or Equation 19.33 with appropriate coefficients) to obtain q_u = 305 cfs. Using Equation 19.31, the peak discharge for predevelopment conditions is:

$$q_p = (305)\left(\frac{50}{640}\right)(2.3) = 55 \text{ cfs} \qquad (22.19)$$

2. An inflow hydrograph (i.e., direct runoff hydrograph) is needed to design the principal spillway. To determine the inflow hydrograph, the CN and t_c for postdevelopment conditions are needed. The weighted CN value is:

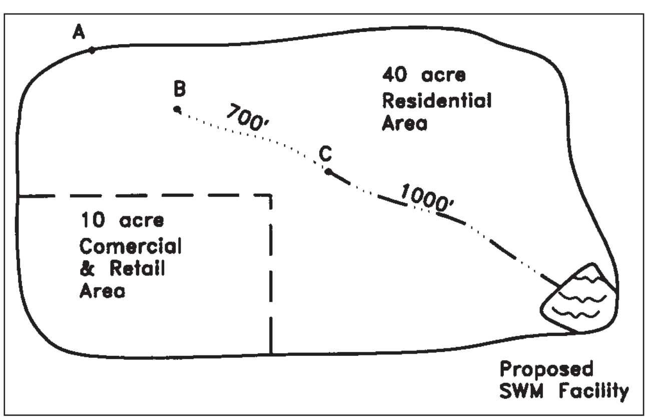


FIGURE 22.36 Fifty-acre parcel for detention pond design.

$$CN = \frac{92\ (10\ \text{acres}) + 68\ (40\ \text{acres})}{50} = 73 \qquad (22.20)$$

The decrease in impervious area for the postdevelopment condition results in a decrease in t_c and, consequently, an increase in peak runoff. It is reasonable to assume a 50 percent (or more) decrease in the length of the flow path for both overland flow and shallow concentrated flow due to the increase in imperviousness and the addition of pipes and inlets. For overland flow computation estimating L = 100 feet and assuming there is nominal change in ground slope, the overland flow time for postdevelopment conditions (assuming n = 0.24; i.e., dense grasses listed in Table 19.12) is:

$$T_t = \frac{(0.007)\ [(0.24)\ (100)]^{0.8}}{(4)^{1/2}\ (0.035)^{0.4}} = 0.13\ \text{hour} \qquad (22.21)$$

The initial 700-foot length used for shallow concentrated flow travel time will undoubtedly be changed. Assume the preliminary plans show that the length for postdevelopment conditions is 100 feet and also that there is little change in ground slope. The postdevelopment travel time for shallow concentrated flow is:

$$V = 20.3282\ (0.02)^{1/2} = 2.9\ \text{fps} \qquad (22.22)$$

$$T_t = \frac{100}{(3600)(2.9)} = 0.01\ \text{hour}$$

In computing the travel time for postdevelopment open channel flow, based on a preliminary layout, part of the flow path will be in pipes and also part of the existing stream will be improved to increase capacity. If the length of the flow path in pipes is estimated to be 450 feet with an average diameter of 2 feet, the travel time in the pipes is:

$$V_p = \frac{1.49}{0.013}\left(\frac{2}{4}\right)^{0.67} (0.02)^{1/2} = 10.2\ \text{fps} \qquad (22.23)$$

$$T_t = \frac{450}{(3600)(10.2)} = 0.01\ \text{hour}$$

The preliminary design projects the improved stream to be increased in size to 5 feet wide and 3 feet deep ($n \approx 0.02$), with a new channel length of 700 feet. The corresponding travel time is:

$$V_{st} = \frac{1.49}{0.02}\left(\frac{(5)\ (3)}{2(3) + (5)}\right)(0.008)^{1/2} = 8.2\ \text{fps} \qquad (22.24)$$

$$T_t = \frac{(700)}{(3600)(8.2)} = 0.02\ \text{hours}$$

The t_c for postdevelopment conditions: t_c = (0.13) + (0.01) + (0.01) + (0.02) = 0.17 hour.

3. The inflow hydrograph is computed using the TR-55 tabular method. As with the predevelopment peak discharge computations, values of S, Q, I_a, and I_a/P are required. The results are shown in Figure 22.37. (Note that the tabular method applies only to 24-hour storm durations). From the inflow hydrograph, the runoff peak discharge is 190 cfs.

In order to get an initial estimate of the storage volume needed, draw a line from the point where significant runoff begins to the target discharge release rate on the falling limb of the inflow hydrograph. This line represents the rising limb of the outflow hydrograph. The area between this line and the inflow hydrograph represents the storage of the pond. For this example, the initial estimate for storage is about 4 acre-feet (≈ 170,000 ft^3).

Before the pond is graded using this as the target volume, the site is assessed as to the controlling constraint, area, or depth, or perhaps other limitations. For example, since the embankment height is limited to 10 feet, the maximum depth of the water is 9 feet (if 1 foot is allowed for freeboard). Allowing for 2 feet of depth (as a first guess) over the crest of the weir for the 100-year storm sets the weir elevation at 147. This

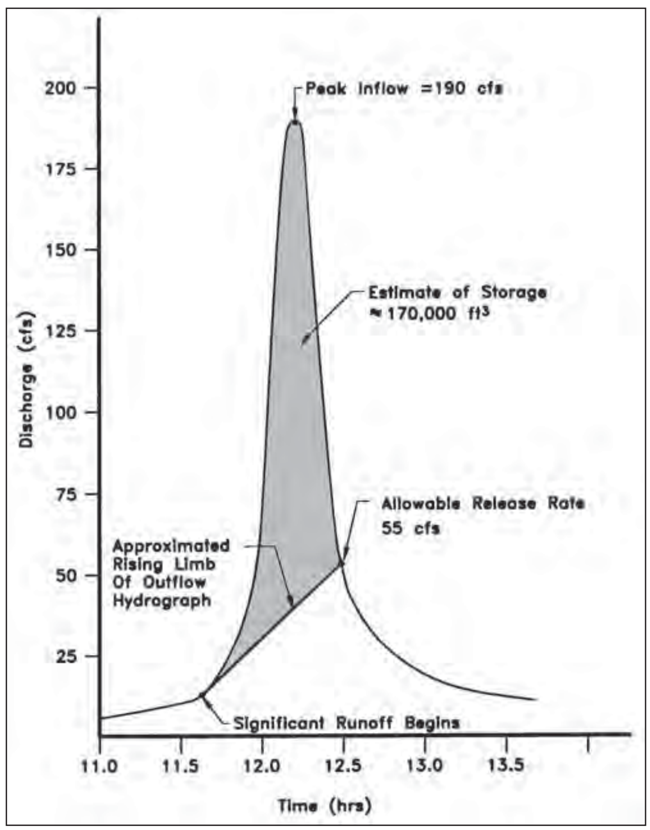


FIGURE 22.37 Inflow hydrograph, annotated to show allowable release rate and required storage.

limits the depth of water over the low-flow orifice to 7 feet. Based on these assumptions the diameter of the orifice is:

$$55 \text{ cfs} = (0.6)(A)(\sqrt{2g7} \qquad (22.25)$$

or

$$A = 4.3 \text{ ft}^2$$

which corresponds to a diameter of 2.3 feet. A 27-inch-diameter hole is selected.

By the same procedure used to determine the predevelopment peak discharge for the 10-year storm, the 100-year/24-hour postdevelopment peak discharge is found to be 362 cfs. (Use P_{100} = 9 inches, weighted CN = 73, and t_c = 0.17 hours.) Using a depth of 2 feet over the crest of the weir determines the length of weir needed to pass 362 cfs.

$$362 \text{ cfs} = 3.0\,(L)(2^{3/2}) \qquad (22.26)$$

$$\text{or } L \approx 43 \text{ feet}$$

To verify the orifice diameter, weir elevation, and length, the inflow hydrograph is routed through the pond. Hydrologic routing using Equation 22.3 is found in most elementary hydrology textbooks. Longhand calculations are tedious, and although it is good practice for an engineer to have performed such calculations at least once, routing calculations are typically done using microcomputers and appropriate software.

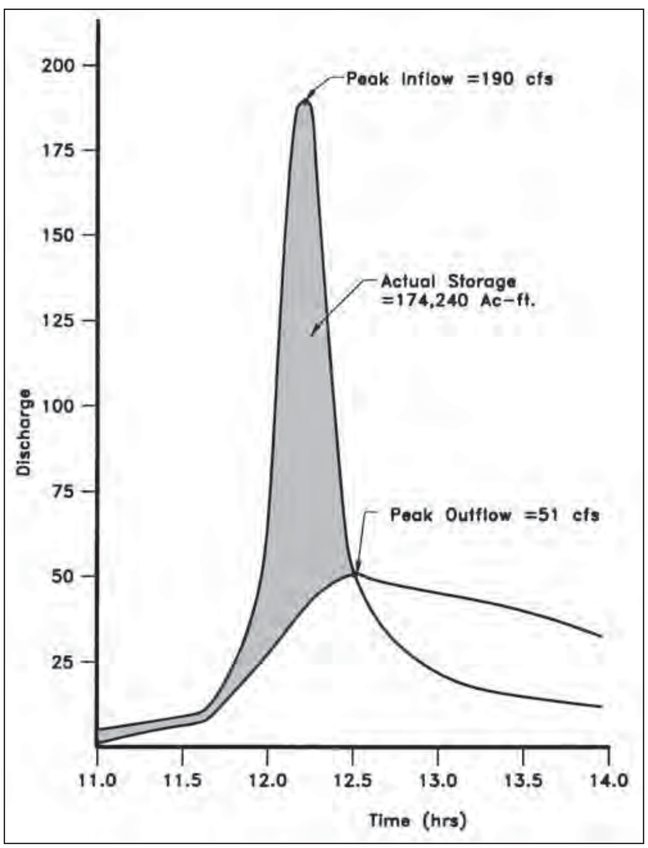


FIGURE 22.38 Inflow and outflow hydrograph annotated to show actual release rate and provided storage.

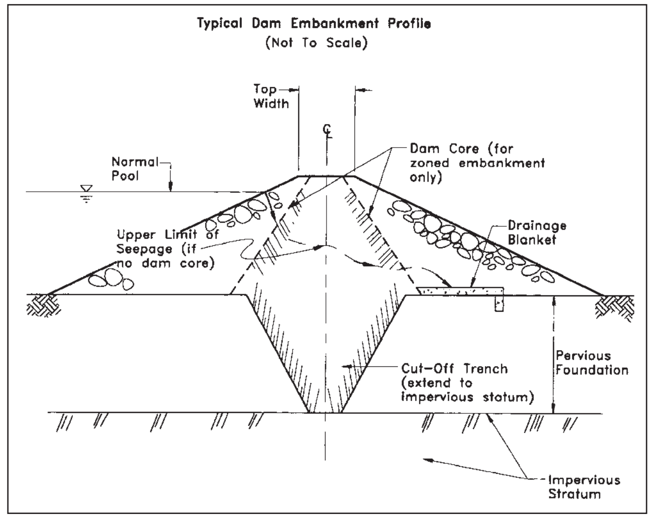


FIGURE 22.39 Typical dam embankment profile showing various geotechnical elements.

Figure 22.38 shows the outflow hydrograph for the routed 10-year inflow hydrograph. Note that the peak discharge of 51 cfs is less than the maximum allowable peak discharge of 55 cfs. The orifice size and/or weir length would have been modified if the outflow peak discharge had been substantially higher or lower than the maximum allowable 55 cfs. Similar procedures are followed if the detention facility is required to attenuate peak discharges for other storm events. Multistage riser structures (those with multiple weirs and orifices) can be designed for this purpose.

Note that this example did not consider any factors that might reduce the flow through the spillway. In the analysis, consideration must be given to downstream tailwater effects that may cause a culvert to function as

TABLE 22.6 Top Width of Dam versus Embankment Height

Total Height of Embankment (ft)	Minimum Top Width (ft)
<14	8
14–19	10
20–24	12
25–34	14

outlet control rather than inlet control or may submerge a weir structure, thereby reducing the effective discharge coefficient.

Spillway Design Considerations

Some items to be considered in designing a spillway structure include the following:

- Reinforced concrete outlet pipes are recommended and must be of sufficient strength to support the embankment fill.
- All joints in the riser and outlet pipe should be made watertight. This is especially important for a wet pond, but it is also good practice for a dry pond.
- The riser should be designed to withstand buoyant forces, with a minimum factor of safety of 1.3.
- Vortex action at the top of the riser should be controlled. An antivortex plate or a headwall may be used to prevent a vortex from forming as the water enters the riser. Antivortex devices often can be incorporated with a trash rack.
- Trash racks or other debris control devices should be used to prevent the spillway from becoming clogged. Trash racks can also be used to discourage children from playing inside risers and pipes. The trash rack should be designed such that for the range of design flows, the average velocity of flow through the trash rack is 2 to 3 fps maximum. An alternative criterion is to design the trash rack with a surface area of 10 times the cross-sectional area of the riser or outlet pipe opening. The Federal Highway Administration's Hydraulic Engineering Circular No. 9, *Debris Control Structures,* gives examples and guidelines for design.
- The outfall channel downstream of the spillway should be protected from erosive velocities of flow exiting the spillway. Riprap lining or energy dissipators may be necessary. The FHWA's Hydraulic Engineering Circular No. 14, *Hydraulic Design of Energy Dissipators for Culverts and Channels,* gives examples and procedures for design.

The slopes of the embankment must be such that the allowable foundation pressure is not exceeded, but flat enough to prevent sloughing. Generally, 3H:1V or 4H:1V slopes are adequate, and they are flat enough that maintenance (mowing, etc.) can be accomplished.

The minimum recommended dam top width is 8 feet. Table 22.6, excerpted from TR-60, gives a list of minimum dam top widths for varying dam heights as recommended by the NRCS. However, the dam top width may need to be increased to meet local standards, allow for different zones of material within the embankment, or allow traffic to cross the dam.

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Some of the references listed here are government documents. In addition to the individual agencies, some of the government publications may be available through the National Technical Information Service (NTIS) or the Government Printing Office (GPO) for a minimal charge. For availability and price, contact National Technical Information Service, (703) 487-4650, and U.S. Government Printing Office, (202) 783-3238.

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CHAPTER 23

GRADING AND EARTHWORK

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Updated/Revised: Susan Weibel, PE

GRADING INTRODUCTION

Grading is configuring the surface of the land by removing or adding earthen material to shape the land to best suit the project. It is accomplished both with large machines, such as bulldozers, pans, and dump trucks, and with men, rakes, and shovels, and constitutes a major component of the function and success of a land development project. See Figure 23.1.

In this chapter, a general overview of the grading process is followed by an explanation of how grading is represented and utilized on plans. A more specific breakdown of grading strategies and requirements follows, providing all the tools needed by the designer to produce an effective grading plan.

A good design integrates the natural landforms of the site with the proposed program to create an aesthetically pleasing yet functional and cost-effective site plan. Because a

FIGURE 23.1 Grading the site. (Photo courtesy of Christer Carshult)

grading scheme must consider function and utility as well as aesthetics, it requires both science and art to create. The grading of a site serves three basic purposes:

1. *Grading re-forms the land surface to make it compatible with the intended land use.* The relative elevations and gradients of streets, buildings, parking areas, and pedestrian/vehicle accesses must be mutually compatible if they are to function as a system. Similarly, they must be compatible with the surrounding existing terrain. Incompatibility with the existing terrain, which leads to excessive earthwork, the use of retaining walls, and drainage problems, increases construction costs.

2. *Grading establishes and controls the new drainage patterns.* In order to be cost effective, the grading design should allow for the efficient collection, conveyance, and detention of stormwater runoff. Proper grading prevents wet basements, damp crawl spaces, foundation damage, eroding hillsides, and muddy stream waters.

3. *Grading helps define the character and aesthetics of the site.* Site design is the foundation on which many other elements of development depend. Proper grading should be cost effective to the developer, appealing to the user, and responsive to the opportunities and constraints offered by the site. In this way, it enhances property value and contributes to the success of a land development project.

Often, the word *grade* refers to the slope, as in "the mountain road has a steep grade." However, the word is also used as a reference to elevation, as in "what is the grade at the top of the driveway?" Both uses are correct, in that grading changes the ground elevation and therefore the inclination of the ground surface.

CONTOUR GRADING

Description of Contour Lines

Contour lines are a method for depicting three dimensions on two-dimensional media, while maintaining a uniform scale in all directions. A contour line is an imaginary line connecting points of equal elevation and is formed by the intersection of a horizontal plane with the ground surface. The spacing and shape of contour lines indicate the shape and the interrelationships of landforms. A natural example of a contour line is the shoreline of a still body of water.

The vertical distance between successive contour lines is the contour interval. Most topographic maps, especially those associated with a land development project, have a constant contour interval. For instance, every contour may indicate a 2-foot change in elevation. Typically, the contour line at every fifth or tenth contour interval is shown as a heavier or darker line to make the map easier to read. In the rare instances where extremely flat areas and extremely steep slopes are shown on the same map, the addition or deletion of contour lines may be warranted depending on the scale of the drawing and the desired level of detail.

While large-scale topographic maps, with 5- to 10-foot contour intervals, are suitable for feasibility studies, smaller-scale maps, with 2-foot contour intervals, are used for final design and detailed studies. These maps are usually produced from recently collected data and provide a more accurate basis for design. State and local agencies, through ordinance and design standards, often require specific contour intervals for drawings submitted for review.

Characteristics of Contour Lines

A key to conceptualizing and executing a grading plan is the ability to visualize the two-dimensional information depicted on the plan in three dimensions. In order to engineer a land development plan, the designer needs to have an understanding of contour lines and be able to recognize the land features associated with them.

All contour lines eventually close on themselves if traced in their entirety. Any apparent break in a contour line is due to the limitations of the map. Contour lines that extend beyond the limits of the subject area terminate at the map edge.

Spacing of contours indicates the general steepness of the ground. Closely spaced contours indicate steep slopes; as the ground slope becomes flatter, the distance between the contours increases. Most natural hills and depressions are convex or concave in shape. A slope is convex-shaped if there is an increase in spacing between contour lines near the crest of the hill. Conversely, a slope is concave-shaped if there is an increase in spacing between the contour lines near the bottom of the slope.

A contour line cannot split, nor can several lines join to form one line. This implies a knifelike edge, which is an unnatural occurrence.

In general, irregularly shaped contour lines designate rough, rugged landforms, while parallel, equally spaced contour lines indicate a smooth, uniform slope—often a machine-graded slope. Note that the steepest slope and also the path of flowing water are perpendicular to the contour lines, an important consideration when establishing drainage divides.

On a relatively large scale, the natural ground line is considered smooth and continuous. Relatively few ground features show sharp, jagged, or abrupt changes in ground relief. This smoothness is carried over to the concept of contour lines. Contour lines indicate distinct elevations, with the actual ground line between contour lines having local areas of irregular depressions and mounds, which may deviate (up to ± 1 foot) from the assumed smoothed ground line, as schematically shown in Figure 23.2. When determining an elevation between contour lines, the ground is assumed straight. Machine-graded slopes tend to be more uniform than natural ground and consequently have fewer irregularities.

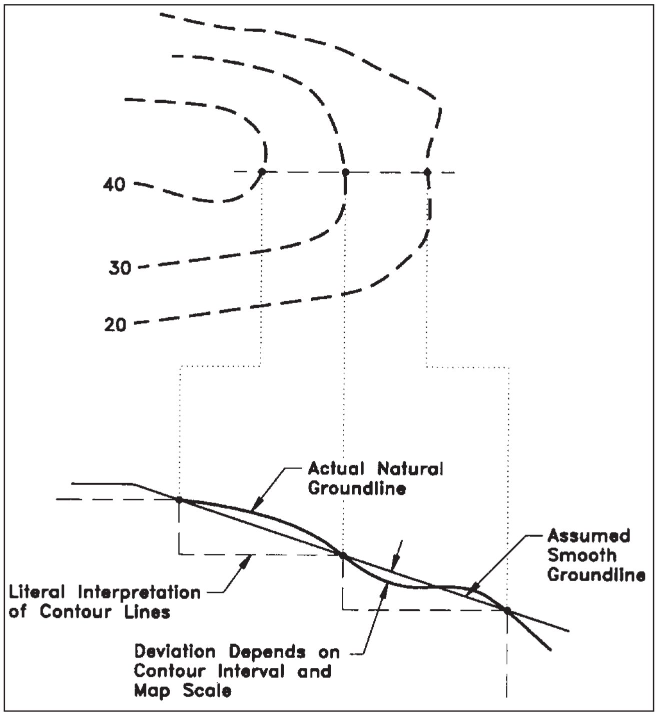


FIGURE 23.2 Irregularities in natural ground.

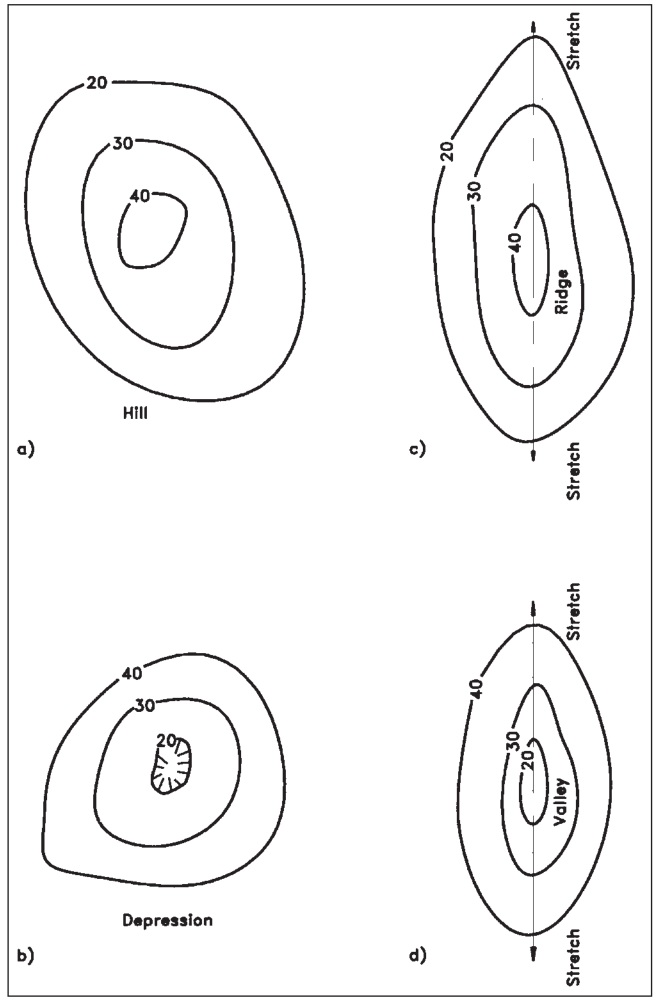


FIGURE 23.3 Contour patterns: hill, ridges, depressions, valleys.

Contour Line Patterns for Natural Surfaces

Hills and Depressions. A series of contours that close on themselves within the mapped area indicate either a localized hill or a localized depression. Figure 23.3*a* shows a hill and Figure 23.3*b* shows a depression. In Figure 23.3*a* the elevations shown on the contour lines increase up to the summit. Conversely, in Figure 23.3*b* the elevations decrease toward the bottom of the depression.

Valleys and Ridges. Valleys and ridges are indicated by contour lines configured in V shapes. Imagine the contours of the hill in Figure 23.3*a* being stretched in one direction. The result is an elongated hill, depicted by contours that are shaped like V's at either end, as indicated in Figure 23.3*c*. The tips of this V-shaped hill, when connected, depict a ridge. Stretching the contours of the depression of Figure 23.3*b* creates the valley configuration of Figure 23.3*d*. Both stretched figures are identical in appearance except for the direction of increasing elevations. To distinguish the ridge from a valley, notice the direction of the apex of the V. On ridges, the V points down ridge (i.e., downhill), while the V points upstream (i.e., uphill) in valleys. Additionally, stream valley contours typically have a sharper V shape, whereas ridges may be in a rounded U-shape.

Overhanging Cliffs. Technically, contour lines never cross. If a contour line represents a single elevation, then intersecting contour lines indicate two distinct elevations at the same point, a physical impossibility. However, in the case of an overhanging cliff, where contour lines may appear to cross, this does not indicate dual elevations, since the two contours are actually in different horizontal planes.

Contour Line Patterns for Constructed Surfaces

Culverts (or Bridges). At the end of a culvert (or bridge) there are, for all practical purposes, two land surfaces to consider. One is at the level of the invert of the structure and the other is the *at grade* above the structure. Typically, the ground will slope up and away from a culvert opening and contours will be parallel and rather close together. In the case of a bridge, which would have a much more complex facial configuration—with possible wingwalls, piers, earth floor, and so on—the grade may not simply slope up and away from the structure as in the case of a culvert. So at the face of a bridge, the contours may appear to cross as two separate ground surfaces are being presented. Figure 23.4 illustrates this concept.

Retaining Walls. Although it is physically impossible for several contours to join and form a single contour line, retaining and exterior building walls can appear in plan view to do just this. For a vertical slope (wall), the space between the contour lines disappears. Consider the face of a wall as a series of contour lines stacked one on top of another, as shown in Figure 23.5.

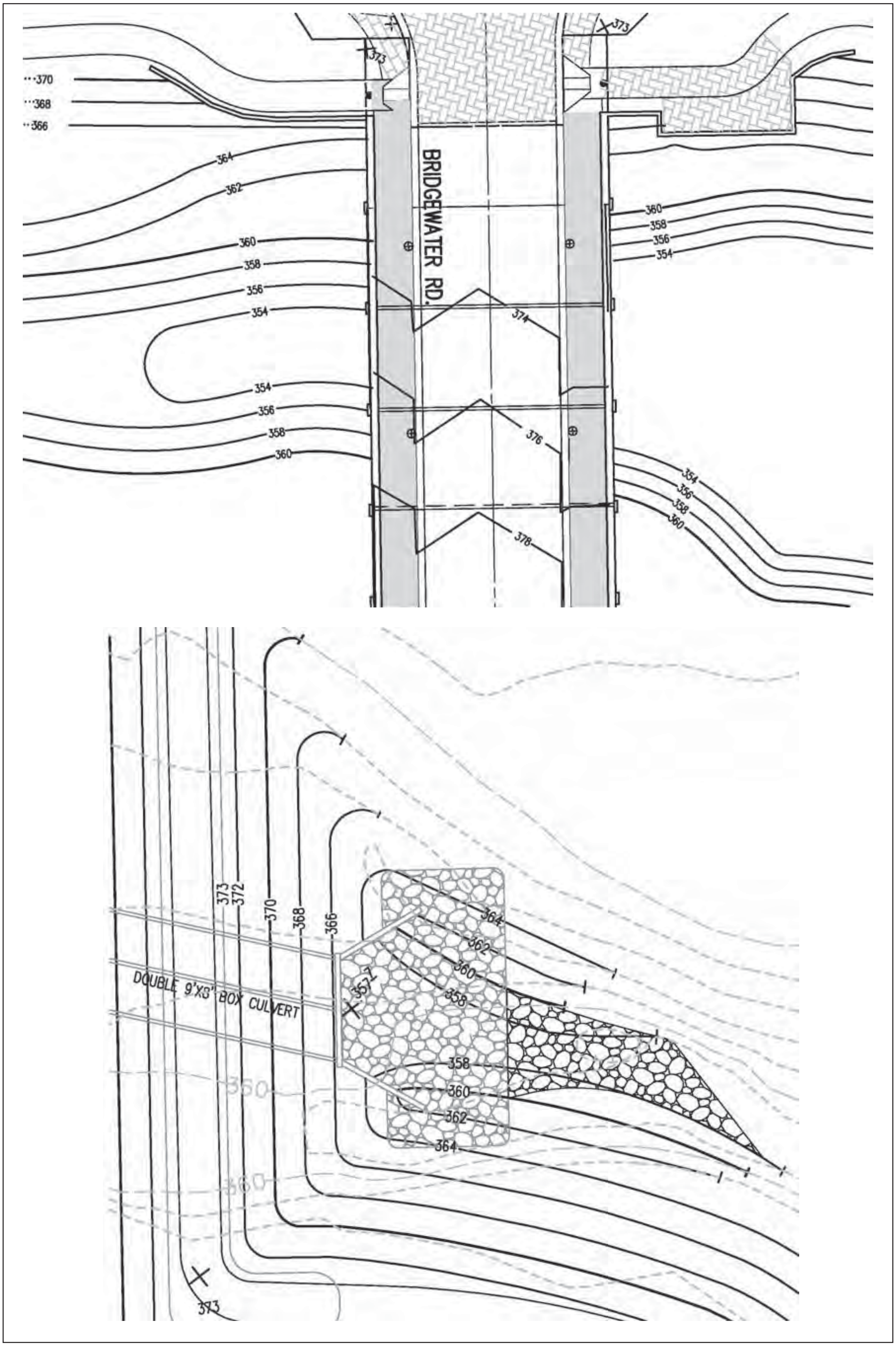


FIGURE 23.4 Contour patterns for culverts and bridges.

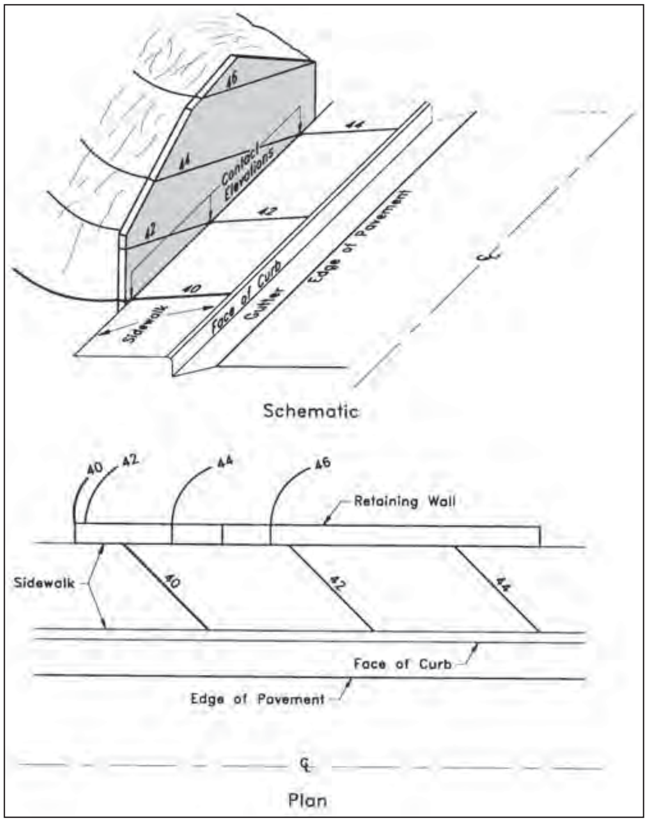


FIGURE 23.5 Schematic and plan view of retaining.

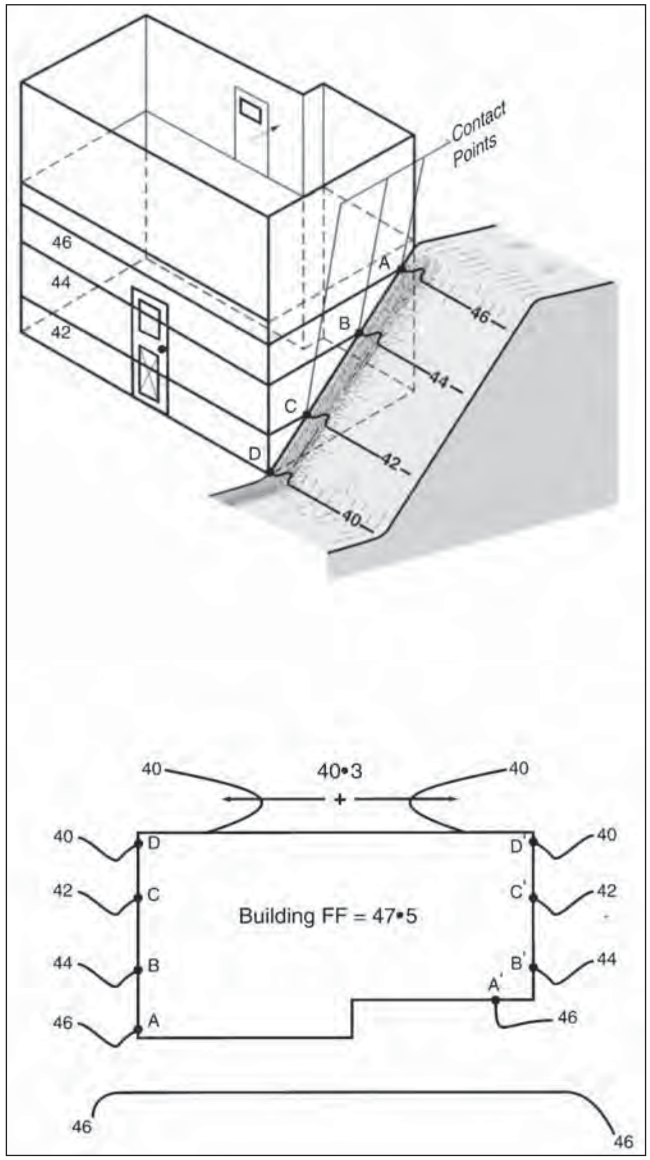


FIGURE 23.6 Schematic and plan view of exterior building.

In tracing the contour line around a wall, the contour line intersects the wall at the contact elevation, that is, where the ground meets the wall, and then continues along the face of the wall. The contour line leaves the wall where the wall intersects the ground at that elevation.

Exterior Walls of Buildings. Exterior walls of buildings serve as earth retaining walls as well as structural support. Similar to the conventional retaining wall, the contour line enters the wall where the ground surface intersects the wall at the prescribed elevation, shown as points A, B, and C in Figure 23.6. The contour line then follows the exposed face of the building wall until it reaches the point where the ground surface is the same elevation, shown as points A′, B′, and C′ in the plan view of Figure 23.6. Since a contour line is continuous, if it "enters" the wall, it must "exit" the wall.

Conveyance Channels. Four frequently used conveyance channel sections are trapezoidal, V-ditch, rectangular, and semicircular. In the plan view of Figure 23.7, each of the channels is 2 feet deep. The depth of the channel is evident by comparing the elevation at the top of the bank with the elevation at the bottom of the channel. On each type of channel section, point A, the top of the bank, has an elevation of 6 feet. A line drawn perpendicular to the flow line, through the top of the bank, intersects the flow line at elevation 04 feet, representing the elevation of the channel invert. Hence, the depth of 2 feet. The V-ditch section shows the V-apex pointing upstream—a quick indication of the direction of flow. Direction of flow in the other channel sections is evident from inspection of the contour elevations.

Another indication of the depth of the channel is how far upstream the contour line runs. The spacing of the contour lines along the sides of the channel is an indication of the steepness of the bank. Figure 23.8 shows a 2-foot-deep and a 4-foot-deep V-ditch with the same longitudinal slopes and the same top widths W. Note how the contour lines extend farther upstream for the 4-foot-deep channel as compared to the 2-foot-deep channel. Because the top widths are the same, the 4-foot-deep channel has steeper side slopes, evidenced by the contour line spacing on the sides of the channel.

Streets. Two types of streets commonly used in development projects are the crown street with curb and gutter and

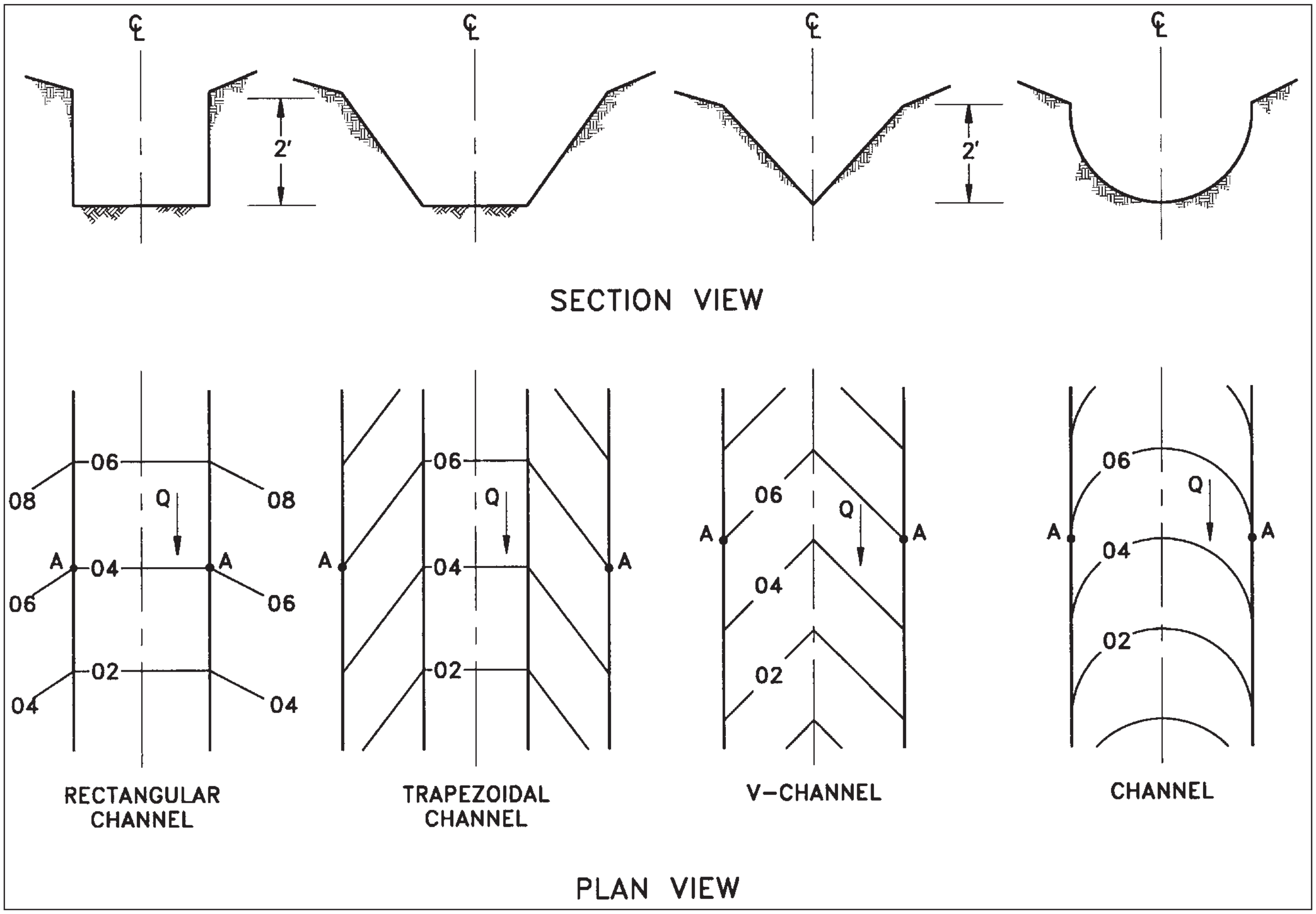


FIGURE 23.7 Contour line pattern for conveyance channels.

the crown street with shoulder and ditch. Figure 23.9 shows the contour line pattern for a curb and gutter street section with longitudinal slope S. For a normal crown section street, the elevation decreases on a line perpendicular to the centerline due to the cross slope of the pavement. From the prescribed elevation on the centerline (point A), the contour line follows a straight-line path that leads uphill until it meets a point at the edge of the gutter (point B) equal in elevation to the centerline elevation.

The break in the contour at the edge of the gutter (point B) results if the cross slope in the gutter pan differs from the cross slope of the street. From the edge of the gutter, the contour line continues uphill to the point on the flow line with the same elevation (point C). The contour line then follows the face of the curb downhill to the point on the top of the curb with the same elevation (point D). In the plan view, the contour line from C to D does not appear since the top of curb, the bottom of curb, and the contour are all superimposed. The contour line intersects the outside edge of the sidewalk at the prescribed elevation. Typically, sidewalks are inclined toward the street. This is apparent from the contour line's downhill direction (points D to E) across the sidewalk. A similar trace of the contour line is shown in the shoulder/ditch type of street of Figure 23.10.

Knowing that water flows perpendicular to the contour line, it is easy to determine the direction of the longitudinal gradient for crown section streets from a quick glance of the contour pattern. Typically, surface drainage on the pavement flows toward the curb and gutter (or ditch), therefore, water flows in the direction perpendicular to the contour lines toward the curb or ditch.

Berms (or Hills) and Ponds. Just as natural hills and depressions display contours that close in on themselves, berms and ponds also have concentric contours. However, manmade features of this nature are typically less irregular and the contours tend to be evenly spaced and/or parallel.

Spot Elevations

Often contour lines alone cannot provide sufficient grading information to detail the existing ground conditions. As a result, the level of precision needed to construct the proposed features detailed on land development plans is not afforded by contours alone. Therefore, spot elevations are used to identify specific elevations at precise locations. For this reason, spot elevations take precedence over contour lines when determining grades.

A spot elevation is indicated in the plan view by a + symbol with the elevation written next to it. Spot elevations iden-

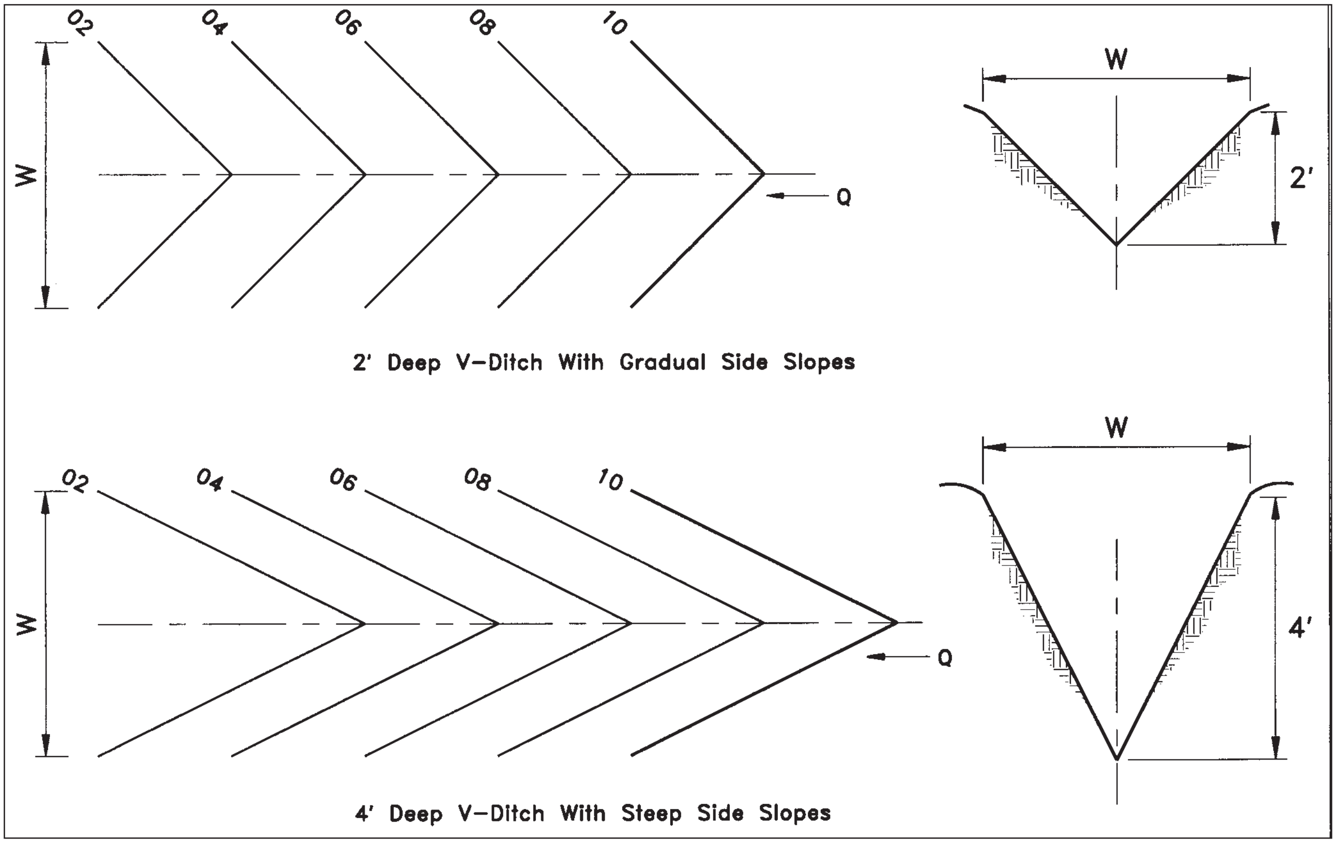


Figure 23.8 Example of 2- and 4-foot-deep channels.

tify discontinuous or abrupt grade breaks in the ground surface, where straight-line interpolation between contours does not give the intended elevation. Therefore, spot elevations are used when the uncertainties associated with scaling distances and interpolating between contours cannot be tolerated.

Typically, spot elevations are used for:

- Precise information regarding the tops of drainage, sewage, and other utility structures
- Identification of high and low points in the grading scheme
- Description of retaining walls, that is, top and bottom of wall elevations
- Elevations at building entrances and corners

Note that spot elevations show up in a profile as an abrupt acute angle at the spot elevation location. The house-grading plan of Figure 23.11 illustrates the liberal use of spot elevations. Abbreviations are written next to the spot elevation when the elevation pertains to a specific feature, for instance, TC = 105.5. Selected abbreviations are given in Table 23.1.

Ground Slope

Ground slope is the rate of change in elevation, with respect to the horizontal distance, commonly expressed as either a percentage or a ratio. The percent slope describes the uniform

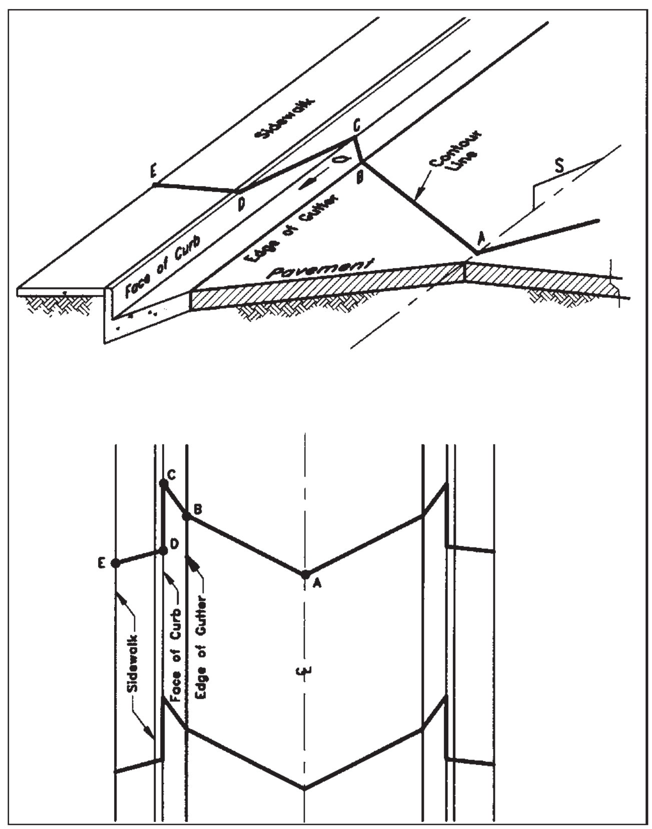


Figure 23.9 Contour line pattern for curb.

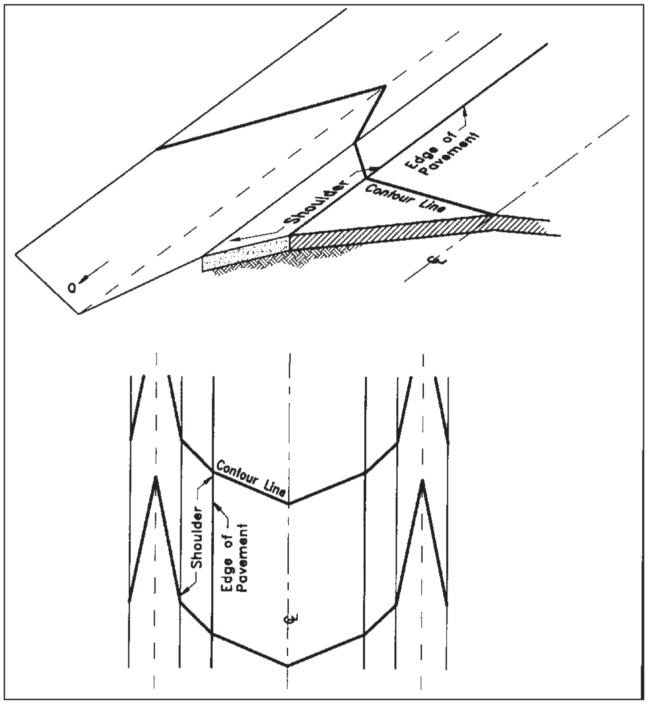


FIGURE 23.10 Contour line pattern for shoulder.

change in elevation for a 100-foot horizontal distance. For example, if elevation changes 25 feet over a distance of 100 feet, the slope is expressed as 25 percent. While mathematically this slope is defined as the ratio of $\Delta v/\Delta x$, where Δv is the change in vertical direction and Δx is the change in horizontal position, that is, a distance H. A simple way to remember this basic tenet is in terms of "rise/run." As a ratio, this slope would be expressed as 4 feet horizontal to 1 foot vertical, or simply "4H:1V." For example, the rate of change in elevation between two points that are 200 feet apart, with corresponding elevations of 100 feet and 150 feet (Figure 23.12), is:

$$\text{Rate of change in elevation} = \frac{\text{Change in elevation}}{\text{Horizontal distance}} \tag{23.1}$$

$$= \frac{\Delta V}{H}$$

$$= \frac{150 - 100}{200} = 0.25 \text{ feet/foot}$$

Hence, for every 1 foot of horizontal distance, the ground changes 0.25 feet in elevation. As a percentage, this equates to a slope of 25 percent; as a ratio, this is equivalent to a

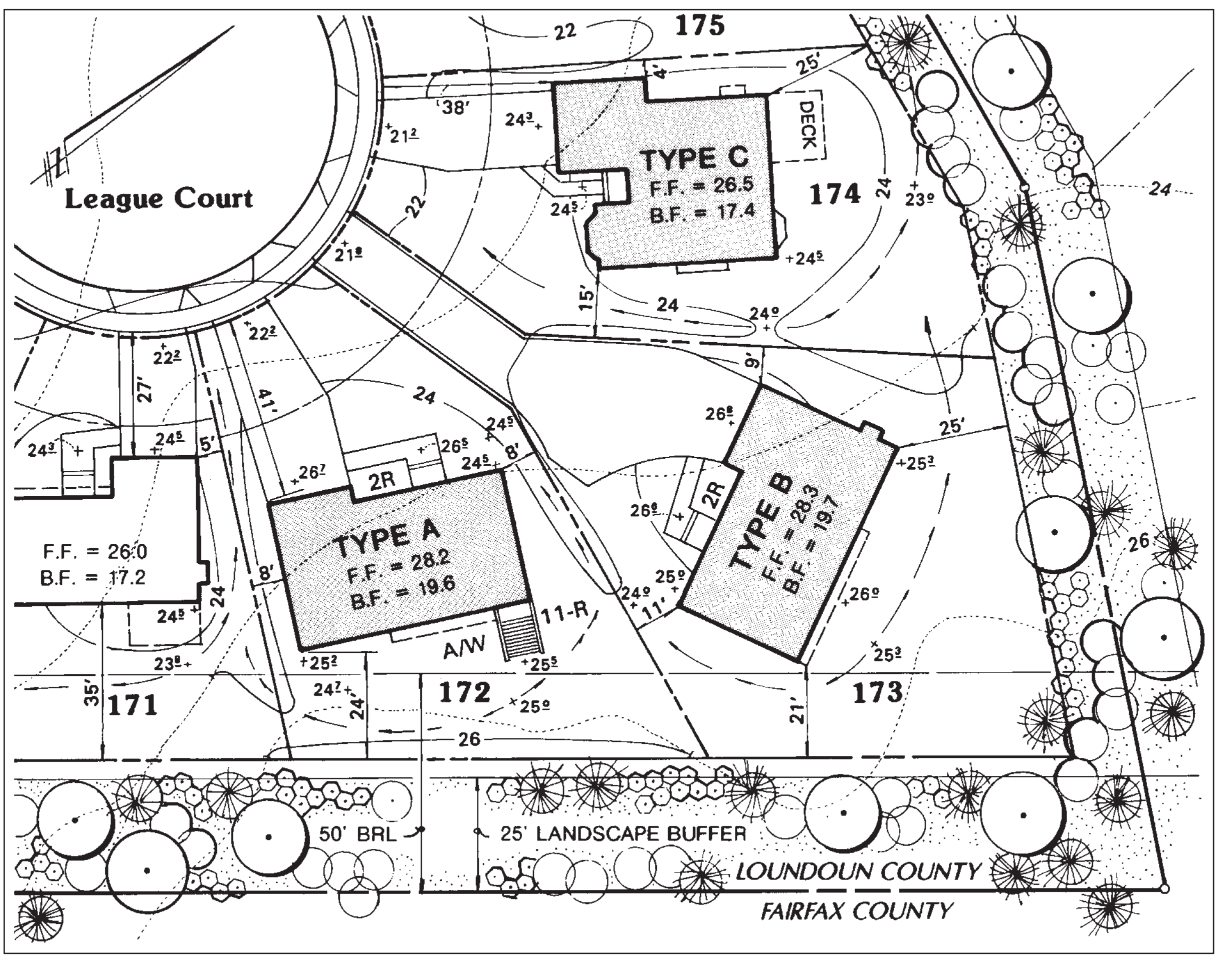


FIGURE 23.11 House grading plan.

TABLE 23.1 Spot Elevation Nomenclature

ABBREVIATION	MEANING
TW/BW	Top/bottom of wall
TC/BC	Top/bottom of curb
FF El.	Finished floor elevation
BF El.	Basement floor elevation
HP/LP	High/low point
Inv. El.	Invert elevation
MH El.	Manhole elevation

4H:1V slope (or 1V:4H). Figure 23.12 illustrates these various means of designating slope gradients.

On most civil site drawings, the ratio is shown as horizontal to vertical, H:V. However, the order is sometimes reversed, V:H, in other professional disciplines (architecture). Because of the significant difference between the two, always verify the order. To that end, it is good practice to include the H and V designation—for example, 4H:1V—or indicate in a note on the plan the correct order.

The specific elevation of any point that lies between two points of known elevation is found by interpolation, presuming the ground slope between the two known points is linear. Hence, the newly determined elevation is based on the average ground slope between the two end points.

Given two end points (A and B) at positions x_A and x_B apart, with elevations El_A and El_B, the average ground slope S_{avg} between the two points is:

$$S_{avg} = \frac{El_B - El_A}{x_B - x_A} = \frac{\Delta v}{\Delta x} \tag{23.2}$$

The distance Δx (h) may be the scaled distance from the drawings or obtained through coordinate geometry if the coordinates of points A and B are known.

$$El_P = El_A + (S_{avg} \times h') \tag{23.3}$$

In Figure 23.13, the elevation at any point P, between A and B and relative to point A, is where h' is the horizontal distance from A to point P. The relative elevation of any point P along h is accounted for by the algebraic sign of S_{avg} as determined by Equation 23.2. In this instance the slope increases going from A to B.

Another way to compute the elevation at any point P is to recognize that triangles APP′ and ABB′ are similar and the ratios of their corresponding sides is a constant, as shown in Figure 23.13. Hence, from the following geometric ratios:

$$\frac{h}{h'} = \frac{(B'B)}{(P'P)} \tag{23.4}$$

the elevation is found by adding (or subtracting, depending on the relative slope) the distance PP′ from the elevation.

Typically, the h measured is the shortest distance between the two points and, as a result, produces the steepest gradient between the two points. However, the horizontal distance measured between the two points may be more circuitous if the situation warrants. For instance, the average slope may be desired along a curb return or along a winding stream channel. Figure 23.14 provides an example of interpolating between contours to determine the elevation of a point.

ESTABLISHING THE GRADING PLAN

A grading plan is established through refinement of different schemes over the course of several trials. The first layout is rarely the best or accepted by the developer. During the first few trials, grades are adjusted to accommodate site constraints, earthwork, different building designs, and the preferences of the developer.

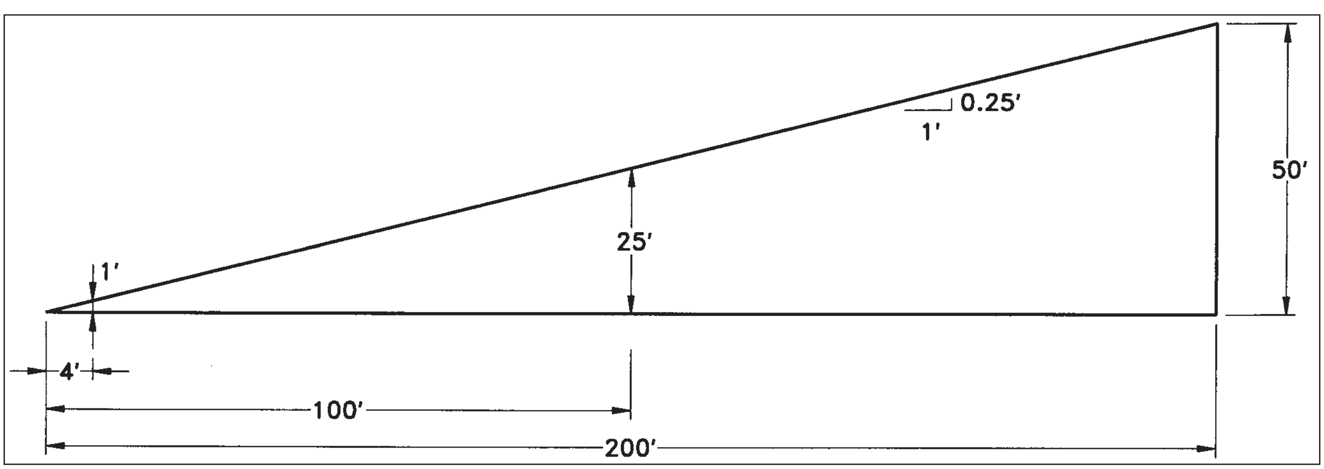


FIGURE 23.12 Various ways to denote slope gradients.

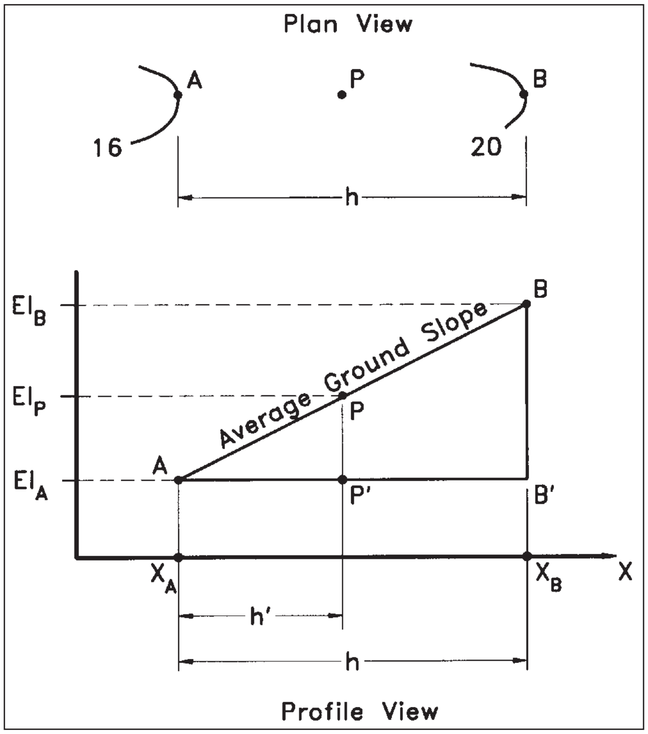
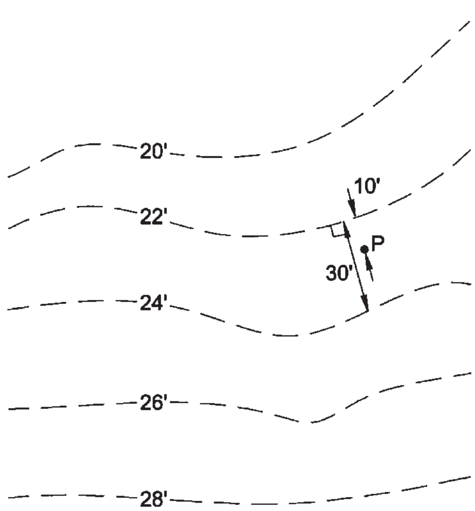


FIGURE 23.13 Interpolation using similar triangles.



Step 1: Determine the average slope between contours

Δv/Δh = 24' - 22' = 2'/30'
= 0.067'/ Foot or 6.7%

Step 2: Determine the elevation at point P

0.067'/ Foot x 10' = 0.67'
0.67' + 22' = 22.67 ≈ Elev. @ P

FIGURE 23.14 Working with contours.

At the very beginning of the project it should be determined whether the site will be designed to meet LEED certification criteria. Although many of the U.S. Green Building Council's recommendations apply to building construction, there are specific credits that apply to site work. Credit 5.1: Protect or Restore Habitat is one such requirement that may be met with a well-designed grading plan. The concept of this credit is to minimize the amount of native soil disturbed when developing a site, or in the case of redevelopment, existing impervious areas would be reduced and native plant material would be reintroduced to the site. To achieve this credit, the designer would need to supply very specific limits of work for the proposed grading. For example, no grading would be permitted farther than 40 feet from the main building.

During the schematic phase of design, the site designer obtains general criteria regarding the size; limitations on horizontal and vertical placement; location of garages, patios, decks, and loading docks, and other constraining information about the main structures that impact the grading design. During preliminary engineering, several layouts and rough grading plan designs might be necessary to optimize the site. For residential sites, the preliminary lot layout provides information on the number of blocks, the number of units in each block, and a rough idea of the vertical arrangement of the units. From these preliminary studies, the architect develops the final arrangement of the units.

During final design, the site designer determines the floor elevations of the main building(s) or housing units. The architectural drawings guide the site designer in setting the floor elevations. Some refinement of the elevations shown on the preliminary plan is necessary at the final design stage. Whereas the preliminary study may have shown elevations to the nearest foot or half foot, final design drawings show floor elevations to the nearest hundredth of a foot. Therefore, deviations from the preliminary design are expected. In addition, the architect's drawings may also have to be refined during final engineering design. Occasionally the architect allows some flexibility in adjusting the vertical and horizontal orientation of individual housing units. Adjusting units several inches or even a foot or two may present no critical dilemma. When vertical separation between units is 2 feet or more, small retaining walls are required.

The design is often done by hand on tracing paper, but may be laid out in the computer in a digital format. The first few schemes may involve only siting the building, showing spot elevations at critical locations, and drawing several proposed contour lines. Additional detail is added to new iterations as the grading scheme is further refined. Once refined to the desired comfort level, the grading needs to be compiled in a reproducible format so that the designer can make work prints and distribute to other members of the design team. Whether the grading was accomplished by hand drafting or through a digital application, it needs to adhere to general industry-wide graphic standards for both symbology and neatness to be effective.

In practice, lighter, dashed lines are used for existing contour lines, while darker, solid lines are used to represent proposed contour lines. Note that the local jurisdiction may have specific graphic requirements for plans that should be considered as well. Additionally, drawing the existing contour lines on the back of the reproducible (Mylar or other hand-crafted formats) while placing the proposed contours on the front makes changing the proposed grading scheme easier. In a digital format, a variety of methods may be used to keep proposed information separate from existing. Either way, the goal is to create an easy-to-read plan that adheres to sound drafting principals.

Grading for Residential Purposes

Consumer appeal for a subdivision or a particular house type depends on numerous factors, one of which is appearance. The layout of the lots and houses, the style and type of the houses, as well as their spatial arrangement affect the overall appearance of the development and combine to form its character.

Frequently, residential land development projects incorporate several different house types and styles within a small price range. This practice is done for three reasons:

1. To accommodate the varying needs and the aesthetic tastes of buyers. The various house designs attract a wider range of consumers, thereby enhancing sales.
2. To take advantage of the varying topographical features of the lots. This provides the developer flexibility in the layout of the houses, which reduces some of the construction costs.
3. For energy efficiency (see Chapter 11, Figure 11.06. Different house types offer varying responses to local climatic, slope, and orientation factors.

After all the houses are set on the lots, the engineer should notify the developer of the proposed mix of house types, since many developers know from experience what mix will be successful. In fact, sometimes the developer gives the engineer a range on the mix before any grading plan is started. Nonetheless, the engineer should verify the mix of house types to be sure no change to the developer's program has occurred before proceeding with the project.

House Type and Foundation Type. The architectural features and configuration of a house categorize it with a particular time period or region—for example, Colonial, Cape Cod, or Victorian. Classification of a dwelling by the arrangement of floor elevations, location of entrances, location of walls, and relationship to property lines (e.g., one-story, two-story, basement walkout, and single-family attached and detached) is also common.

Not only is it imperative that the engineer developing the grading plan know the house types available in a subdivision, but he or she must know the location and elevation of entrances, windows, garages, decks, patios, and roof lines. The engineer must consider each lot individually as well as collectively to determine the optimal spatial arrangement of the houses along the street and within the development. In many suburban developments, the cost of land and the demand for greater living space results in building larger houses on smaller lots. The higher density produces a higher yield for the developer, which in turn keeps housing costs down by reducing infrastructure costs on a per-unit basis. However, smaller lots put houses in closer proximity, making house orientation a very important consideration. The designer must consider the views from one house to another, avoiding direct lines of site from one house into intimate areas of another house. For instance, no one wants to look out his front door and see into the dining area of the next house or, worse, peer into the window of a second-floor bedroom. Although grading can be used to diminish the effects of poor siting, a good layout is paramount to a development's success.

Spatial arrangement is part of what is known as the *streetscape*. Setbacks, rooflines, utility corridors, street trees and landscaping, sidewalk and trail locations, and signage further define the streetscape. These elements work with the grading to lend the development a uniform character and create a cohesive, unified design.

A residential lot can be categorized according to the direction of the ground slope, using the front property line as reference. A downhill lot is one in which the ground slope falls away from the front property line. An uphill lot has ground sloping upward from the property line, while a side-to-side lot has slopes across its width. Efficient land use includes the selection of a house type that is compatible with the terrain. Proper design and siting of the house minimizes earthwork and reduces the disturbed area, which helps the environment and saves on construction costs.

For grading purposes, it is useful to categorize the myriad of housing styles by asking the following three questions: (1) Is the unit single-level or split-level? (2) Does the unit have a basement? (3) Is it a single unit or are several units attached (town houses)? The answers to these questions help determine how the lot(s) will be graded.

Single-Level or Split-Level. A single-level unit is constructed so that the finished floor elevation is the same everywhere. Floor elevations of a split-entry house are staggered such that their access from a preceding level is less than the full flight of stairs typical of the common two-story unit. Split-entry houses and their variations are ideal for all types of hilly lots. These houses work best when the grade difference across the lot is 2 to 4 feet. Houses in this category are frequently referred to as split-levels and split-foyers. Split-level houses have a combined slab and basement foundation system, as shown in Figure 23.15. Similarly, the basement of a split-foyer is partially exposed. Figure 23.15 shows the basic house types and their corresponding foundations.

No-Basement or Basement. No-basement types of buildings are built on a concrete slab or crawl space and are best

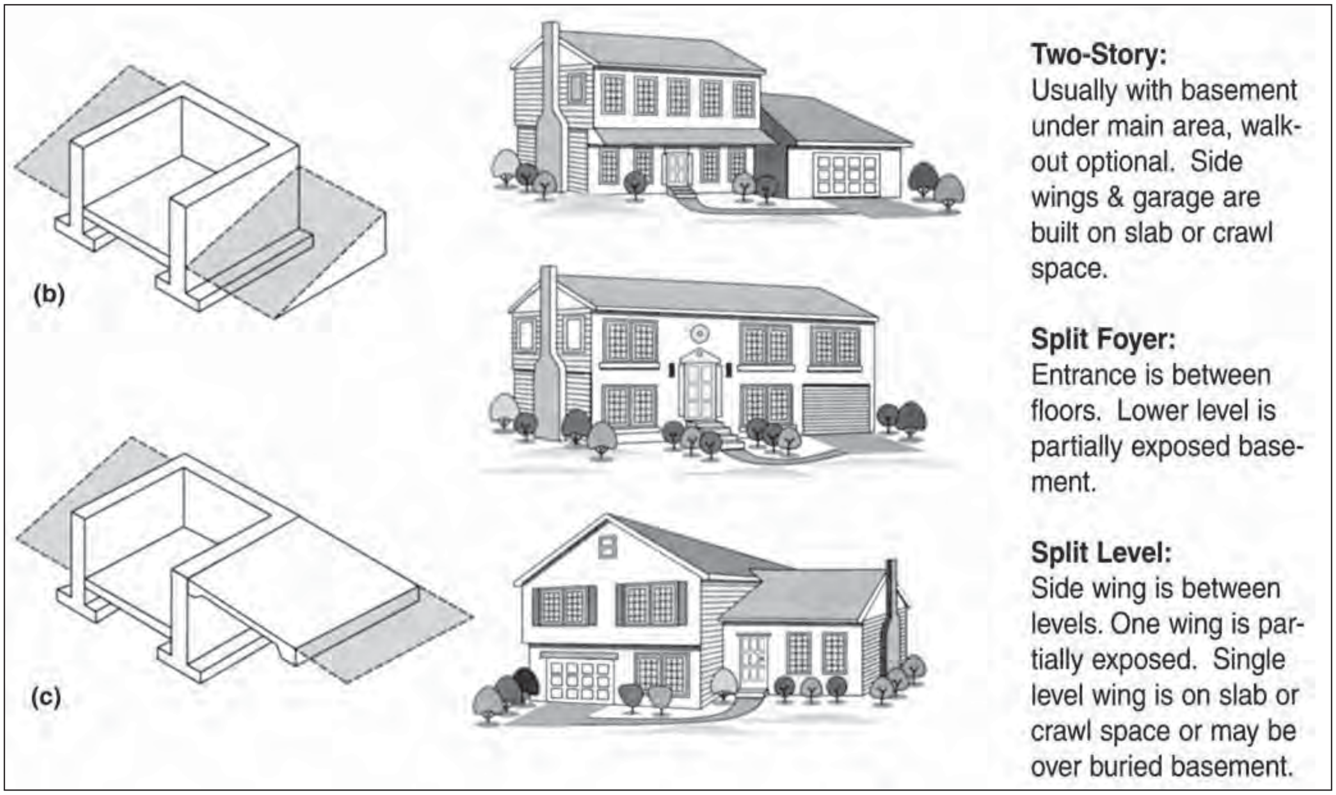


FIGURE 23.15 Basic house types and their foundations.

suited for flat areas with high water tables or where extensive rock lies near the surface. They are generally less expensive due to savings in excavation and construction costs. They are less suitable for hilly sites, since they require more grading to accommodate the building footprint. The no-basement unit is common in many regions of the country, and virtually every style of house can be constructed without a basement.

That part of the house that is wholly or partially buried is the basement. Basement units are useful on hilly lots because of their ability to accommodate grade differences. For instance, the house shown in Figure 23.15*b* has a grade change of about 4 feet from front to back, which may enable the proposed grade to tie in with the existing grade sooner, thereby reducing the disturbed area.

In addition to enabling the house to better blend in with the site, the use of basements can also generate small amounts of excess dirt that can be used elsewhere on a project. If a site is slightly deficient in fill dirt, basements can be incorporated to make up the deficiency. The use of basements also increases the living space of the house. This living space is enhanced by the presence of natural light, so often a partially buried basement that allows for window space is better than a completely buried basement. Another design element that enhances basements is the walkout, which provides direct access outdoors from the basement. The typical site layout for a walkout is depicted in Figure in 23.16.

Town Houses. Town house developments consist of parking areas, private streets, open space, and blocks of attached residential units. Typically, the blocks, or sticks of residential units, contain three to nine homes. The interior units share a wall with either neighbor, while the end units have only one wall common with an adjoining unit. Typically, the property line runs down the center of the common wall.

Although a block of town houses may have several house types, variations in architectural style, and different lengths, usually they have a constant width. These variations help prevent the visual monotony that would occur if all the houses aligned and had the same style (see Figure 23.17). Other variations include vertical and horizontal staggering, which provides flexibility in the layout and helps the sticks conform to sloping sites.

Since each unit is attached to another unit within a block, there must be coordination in the structural design with adjacent units (e.g., rooflines, wall framing, etc.). The minimum or maximum variations in horizontal and vertical relationships may be dictated by local ordinance and building codes. Certainly, restrictions on staggering and vertical orientation are limited to the structural and architectural design.

From an engineering aspect, the units have to coincide with the site constraints. Yet from a sales perspective, the units have to be appealing to consumers. For this reason, the layout and design of a town house project requires extensive

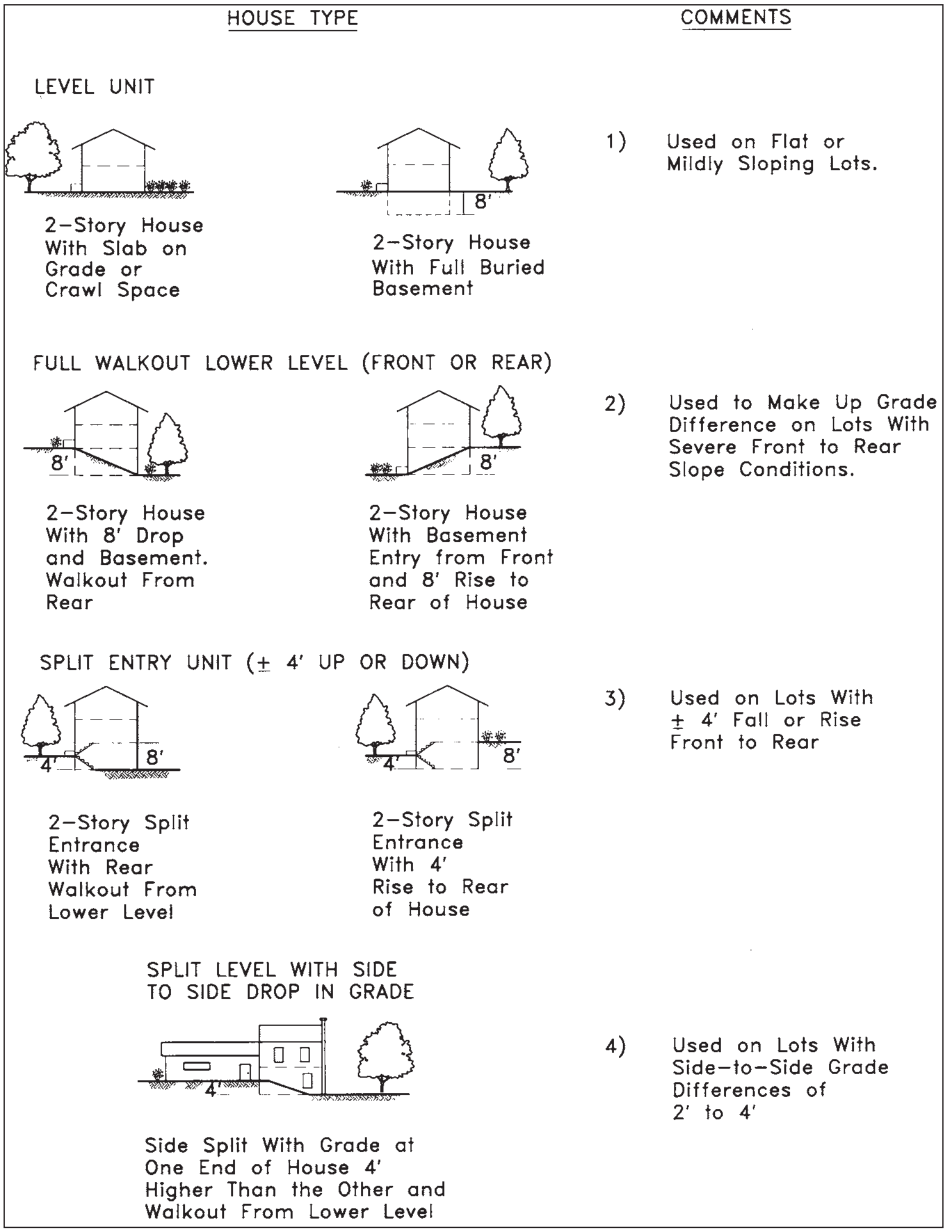


FIGURE 23.16 Selection and location of building types to fit natural landforms.

communication and coordination among the site designer, developer, and architect.

Setting the floor elevations for town houses is more involved than for single-family detached houses. A certain limited structural relationship, evident from the architectural plans, exists among the units of a block. Some town house designs allow for the flexibility to adjust the stagger distance and the vertical relationship of floor elevations of adjacent units. This flexibility is needed to allow for better coordination between the housing units and the site conditions.

To set the town house elevations properly, the engineer needs a complete current set of architectural plans. From these plans, the site designer determines the relative location of the units in a block. As with single-family homes, a template of the town house block may simplify the process. This template shows the relative floor elevations of the units and the location of stoops, patios, decks, and other appurtenances. When vertical adjustment between units is necessary, it is recommended, and usually mandatory with brick veneer, to raise or lower floor elevations in 8-inch increments. This recommendation is based on the dimensions of masonry units used for construction. Using 8 inches or a multiple of 8 simplifies the construction while still providing flexibility to the designer.

Depending on the experience of the site designer and architect, the site designer may be the one who sets the pad elevations and staggers the setbacks. This information is

FIGURE 23.17 Town house block showing vertical stagger. (Courtesy of Sutton Sullenberger Yantis Architects)

then sent to the architect, who then develops the block designs. Whether the site designer suggests the initial unit requirements to the architect first, or vice versa, communication between the site designer and the architect (through the developer) is imperative to exchange the interdisciplinary information necessary for design.

Another problem encountered in setting town house elevations is the number of risers (steps) from the street to the door. The site designer needs to verify the horizontal and vertical distance necessary to accommodate the full run of the stairs. Zoning ordinances may not allow the steps and stoop to encroach into the building setback limits. The site designer must verify that the vertical distance from the door (or stoop) to the ground, and the horizontal distance from the door (or stoop) to the property line, is capable of accommodating the required number of risers. A safe assumption is to allow a tread width of 1 foot; therefore, if 10 risers are needed, the minimum setback to the stoop is 10 feet. Furthermore, additional distance may be needed between the sidewalk and the start of the steps. Although riser heights can vary, the maximum height is typically limited to 7½± inches; building codes require the riser height to be constant for the run of steps. Therefore, the vertical distance from the sidewalk/street to the entrance must be a multiple of the riser height.

Siting the House. When siting a house on a lot, one must position the house horizontally and vertically in a manner harmonious with the surrounding structures and terrain, while ensuring compliance with all appropriate codes and ordinances.

Character of the Site. In most residential single-family detached subdivisions of moderate density, siting a house is limited to the lot layout of the subdivision and the orientation of the street. Presumably, solar exposure and compass orientation were considered when the lot and street layout were established in the concept and schematic design stages, since there is not much practicality in orienting the house for energy efficiency if it contradicts with the street and lot layout.

Further, the topography of the lot and any (aesthetic) constraints by the client play a part in selecting a house type (see Figure 23.16).

Property Lines and Setbacks. In addition to size and the type of lot (corner, flag, etc.), its applicable setbacks play a part in how a house is sited. Usually, the engineer portrays an exact footprint of the builder's house on a proposed lot, precisely measures its distance to the property lines, and produces a lot grading plan.

Grading the Lot. There are two types of grading schemes: lot grading and block grading. Lot grading involves only one building and one lot. Grading is limited to the constraints at the boundaries of the lot, and any grading beyond the lot requires permission from that owner. Typically, lot grading applies to infill projects and commercial projects. Block grading involves grading a group of lots, a frequent occurrence in single-family residential projects. Block grading is not bound by the rigid constraints of lot grading, since the whole group of lots is owned by one entity. Additionally, the spatial arrangement and the drainage pattern can be integrated much easier.

Using generic building footprints, the engineer produces the block grading plan, which defines the general grading patterns for groups of lots. This plan verifies the site's feasibility regarding a fairly specific program and is often used by a developer to market the lots to builders.

Drainage. Another controlling factor for setting the house elevation is the street elevation. Typically, the first-floor elevation is above the street, but limitations on driveway grades, as discussed next, may also control the maximum elevation of the house. The relationship of the house to the street is a major factor in its curb appeal, and any deviation from general standards, such as a very steep driveway or slope that drains to the foundation of the house, looks out of place and lowers the curb appeal. Generally, lots are graded such that drainage is directed away from the structure toward the street or other runoff conveyance systems such as swales or channels that may be incorporated into the proposed grading plan.

Driveways. A house set 25 to 35 feet from the street typifies the private driveway entrance. The slope of the driveway should be kept in the range of 2 percent minimum to about 7 percent to 14 percent maximum, depending on whether the driveway is inclined up or down. The following points should be considered for driveway slopes exceeding about 5 percent:

- In snowy climates, steep driveways can become slippery and dangerous.
- If a walkway is proposed from the street to the house, a steep slope may require long flights of stairs, which are expensive to construct and can make the entrance to the house awkward.
- The transition from the street to the drive must be lengthened so that car bottoms don't drag.
- A landing with a slope of 2 percent should be provided in front of the garage that transitions to the steeper grade of the driveway.

Such points of potential concern are illustrated in Figure 23.18.

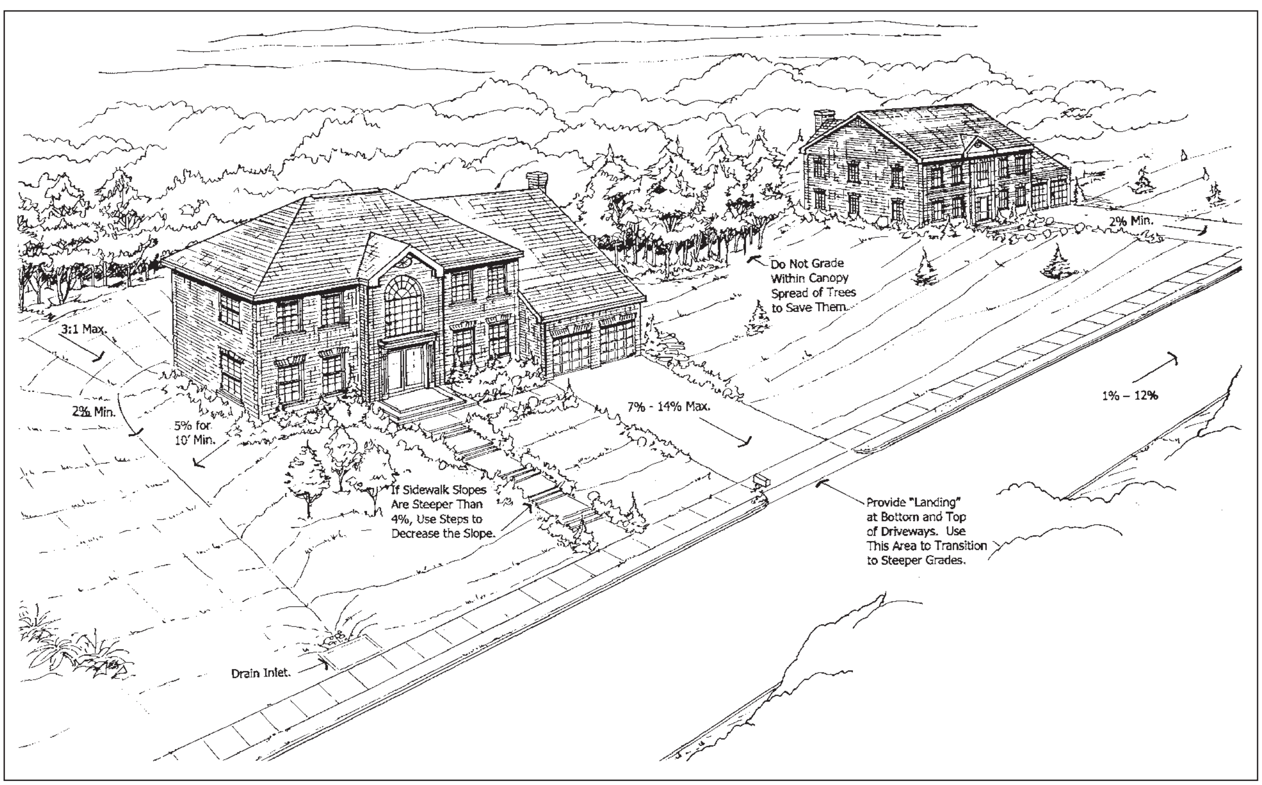


FIGURE 23.18 Illustration of grading strategies for subdivisions.

Utility Services. In addition to the relationship of the house to its lot and surroundings, another relationship that affects the siting of a house is that of the elevation and location of the sanitary sewer. As shown in Figure 23.19, the house should be sited in such a manner as to provide a gravity sewer for the lowest level of the house. A quick way to determine approximate finished floor based on the sewer line elevation is as follows:

1. Determine the invert of the sewer main at the connection point.
2. Multiply the distance from the connection point to the farthest point of the house by 0.0208 (¼ in/ft), and add to the invert elevation (the fall *f* in Figure 23.19).
3. Add the diameter of the sewer main (distance *d* in Figure 23.19).
4. Add an allowance for clearance under the foundation (shown as * in Figure 23.19).

Typically, the house sewer runs under the footing for shallow footings and foundations. Therefore, the elevation of the lowest level should be raised an additional 6 inches to 1.5 feet (depending on local construction practices) to allow for clearance beneath the footing and floors. In situations where it is not feasible to run the house sewer line under the footing, the house sewer line can be run through the footing.

When a basement, because of its depth related to the sewer main in the street, cannot be sewered using a gravity line, the sewer is referred to as a *hung sewer.* A pump may be installed to eject sewage from the basement to the sewer main if it will not flow by gravity, but this practice may come under special regulations in many jurisdictions. Other solutions, such as lowering the sanitary main, might be feasible, but the engineer must consider the impact of such a solution on the rest of the project. Careful planning while designing the grading plan helps prevent awkward situations such as basements that won't sewer by gravity.

Grading around the Unit. Finally, the development of any grading scheme includes the assimilation of other existing data and identification of the constraints it imposes. These existing constraints are combined with the data available on the proposed building structure. Ideally, these constraints are obtained from the approved architectural and mechanical drawings. The location and relative elevations of doors, garages and windows, other appurtenances such as decks, patios, stoops, walkways, and any utility connections are necessary to develop an effective grading plan. This information becomes part of the constraints for grading. From this architectural information, develop a footprint of the building showing all entrances, windows, and other appurtenances at or near the ground level that affect the grading, often called a *template.* The relative elevations of these items with respect to the floor elevations are labeled on the template. Figure 23.20

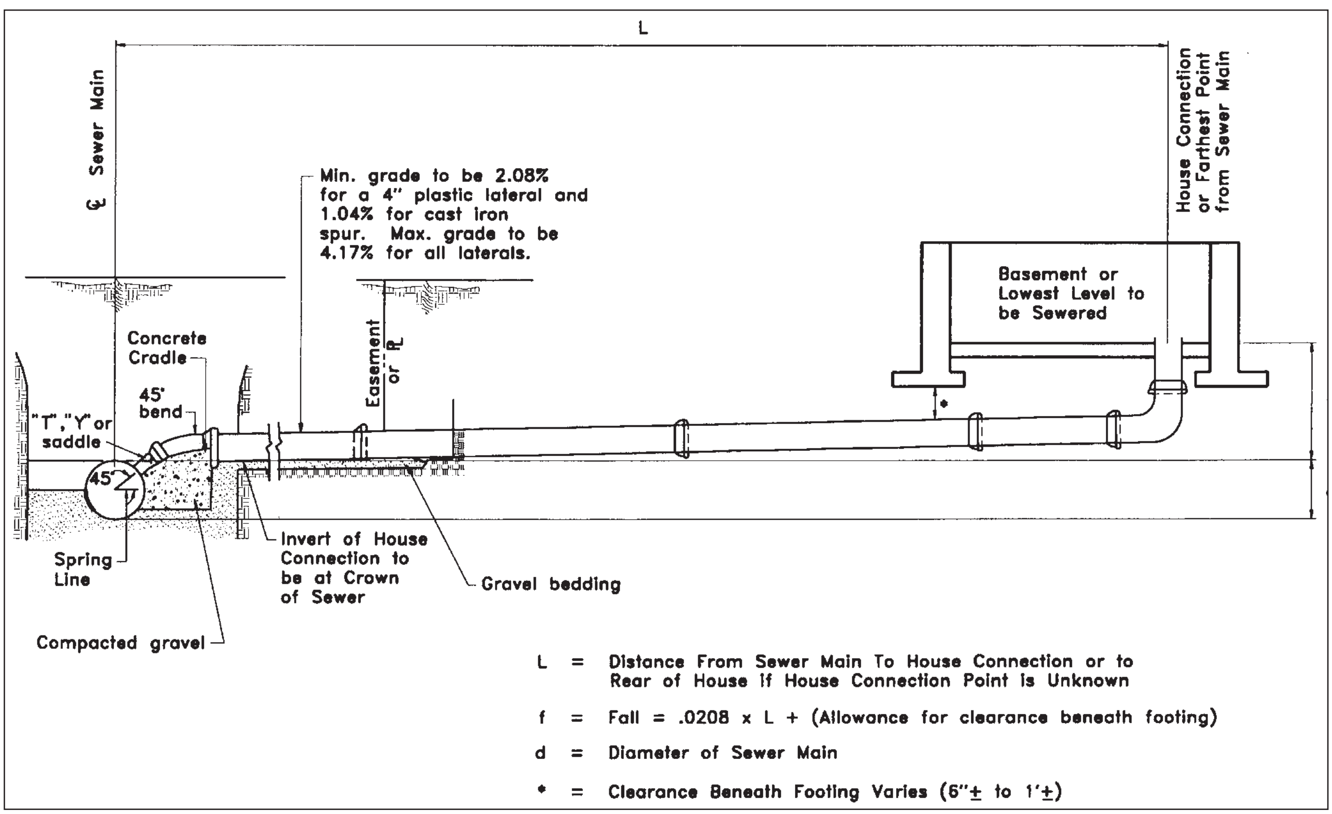


FIGURE 23.19 Sewer line from house to sewer main.

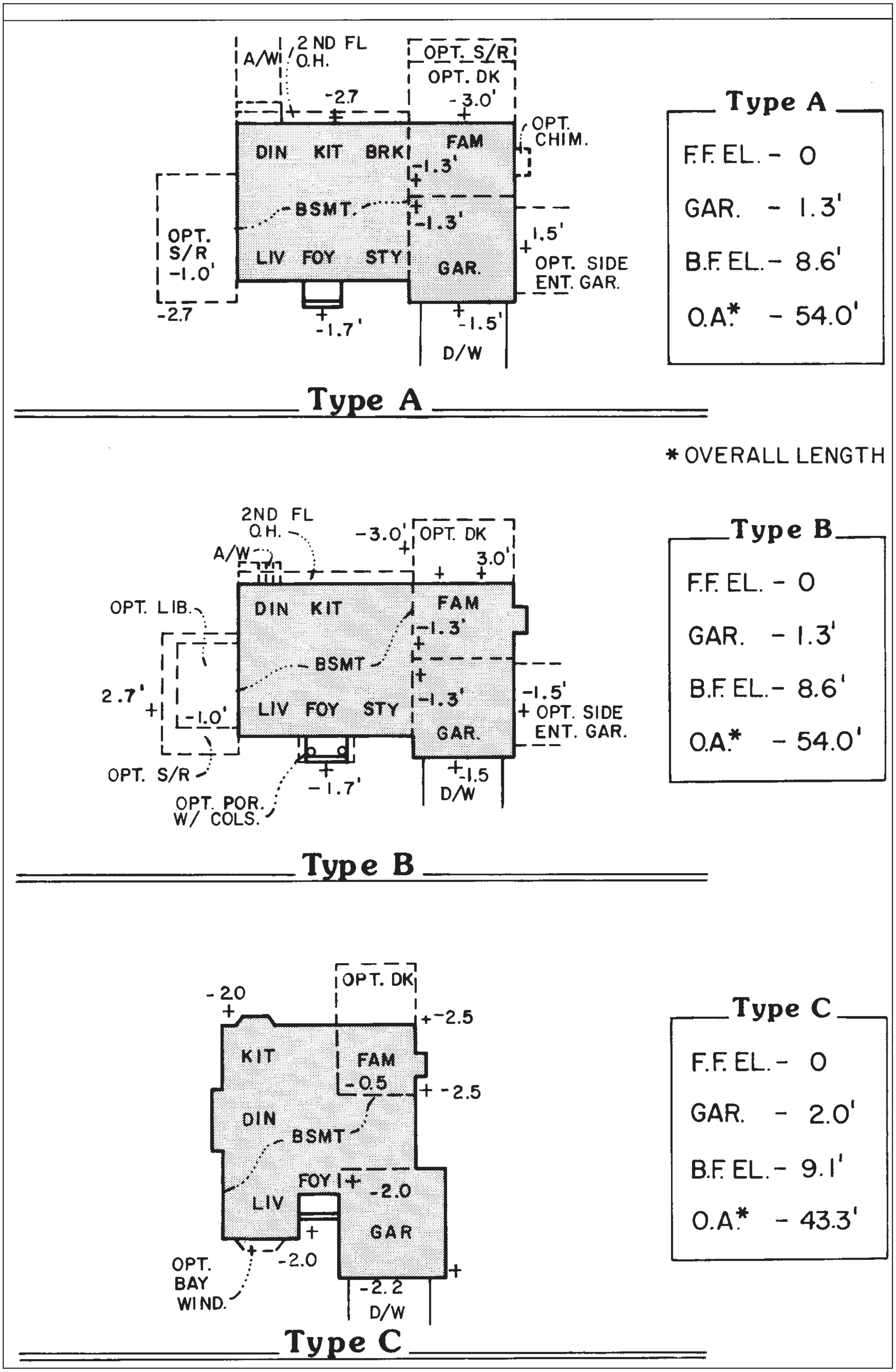


FIGURE 23.20 House template.

depicts examples of house templates for three different house types used on a project. The building template is placed on the grading plan and oriented such that it best suits the topography, ordinance setback requirements, and utility constraints. The specific footprint of the desired house is then transferred onto the grading plan after the best orientation of the template is obtained. Since a typical subdivision has several house styles, the use of templates allows the designer to shuffle the house types around the lots for quick analysis.

Additionally, siting of buildings on corner lots must allow for sight distances of the intersecting streets. This includes high walls and steep slopes resulting from the grading that might impede the required sight distance. However, in most cases the required zoning setbacks and minimum radius of curvature allow for adequate sight distances.

The height of the earth fill around the house depends on the exterior surface and type of foundation system. Soil and accompanying moisture accelerate decay of some types of construction materials and provide a haven for insects that can damage the house. Figure 23.21 shows the relationship of the exterior grade for selected foundation systems. The architectural plans should be consulted for the relationship of the flooring to the foundation wall, since setting the first-floor elevation dictates the maximum ground elevation. The ground elevation around the perimeter of the house is adjusted to account for windows, doors, garages, and other architectural features, all of which are indicated on the house template.

Once the house is positioned on the lot, the elevations at all critical points are shown with spot elevations. Typically, stoop, patio, and ground elevations outside of doors are 6 inches (minimum) lower than the first-floor elevation. Additionally, elevations are shown at windows located near ground level to ensure they are not buried. Walkways leading from the front door to the driveway or street should not be steeper than 5 percent. If walkways become too steep and steps cannot be used, then the overall house elevation may have to be raised or lowered to account for such constraints.

Rear Yard. When grading out a rear yard, the designer should seek to provide an area sufficiently level as a place for lounging and family recreation. A space of 15 to 20 feet by 30 to 40 feet, graded to a maximum of 5 to 6 percent slope, immediately behind the house is reasonably adequate. In areas of steep slopes, where a flat yard of this size would require expansive fill slopes, the size of the backyard may be reduced, with perhaps a large deck proposed to provide the outdoor living space.

Mass Grading. In the case of subdivisions, typically only the infrastructure—roadway, underground utilities, and special features such as berms and drainage ponds or swales—is constructed by the developer. At this point, no homes are built and the individual lots are generally graded slightly lower than final grade. This is referred to as *mass grading*. When a lot is sold and a home is built, spoil from the excavated basement is spread on the lot to raise it to final grade. This not only eliminates the need to remove excess soil from the site when the home is constructed but also prevents adding fill to the site unnecessarily. Therefore, the grading plan for a subdivision should include mass grade elevations for each unit in addition to finished grade elevations.

The process of determining how much lower than final grade a lot should be constructed is one of trial and error. A given drop in grade is chosen and then the volume of spoil and the amount of fill required to bring the lot up to grade are calculated and compared. Several drop values need to be evaluated to determine the ideal drop—the one that results in the volume of spoil and required fill being the closest to equal. Mass grade elevation is determined by Equation 23.5.

$$\text{Mass grade} = \text{Finished grade} - \text{Ideal drop} \tag{23.5}$$

When calculating the volume of basement spoil, the designer needs to consider how the lot is to ultimately be graded. More specifically, will the grade get lower around the rear of the unit to provide a walkout or half-walkout basement? Both of these instances will result in less spoil, as less of the basement will be buried. When calculating the volume of spoil, it is important to remember that the depth of the basement (depth that the basement will be buried when final grades are achieved) needs to be adjusted by the amount of drop being considered. Approximate spoil volume can be determined by using one of the following equations.

a. Non-walkout (23.6)

$$SV = (D_B - \text{Drop}) \cdot A$$

b. Half walkout

$$SV = \left[\frac{1}{2} \cdot (D_B - D_{BI} - \text{Drop}) \cdot A\right] + (D_{BI} \cdot A)$$

c. Walkout

$$SV = \frac{1}{2} \cdot (D_B - \text{Drop}) \cdot A$$

where SV = volume of spoil, D_B = full buried depth of basement (portion of full basement buried at final grade), A = area of basement, and D_{B1} = half-buried depth of basement (portion of half basement buried at final grade).

The process for determining the volume of fill required to raise the lot to final grade is as follows:

1. Draw three contours on the lot. Draw the first (referred to as the *0.0 contour*) just inside the property line or edge of disturbance. The depth of fill is equal to 0 feet in this location, as this is where the finished grade meets existing. However, the mass grade elevation at this location is assumed to be 0.5 feet below the finished grade elevation for the purpose of these calculations. The purpose of making this assumption is to account for

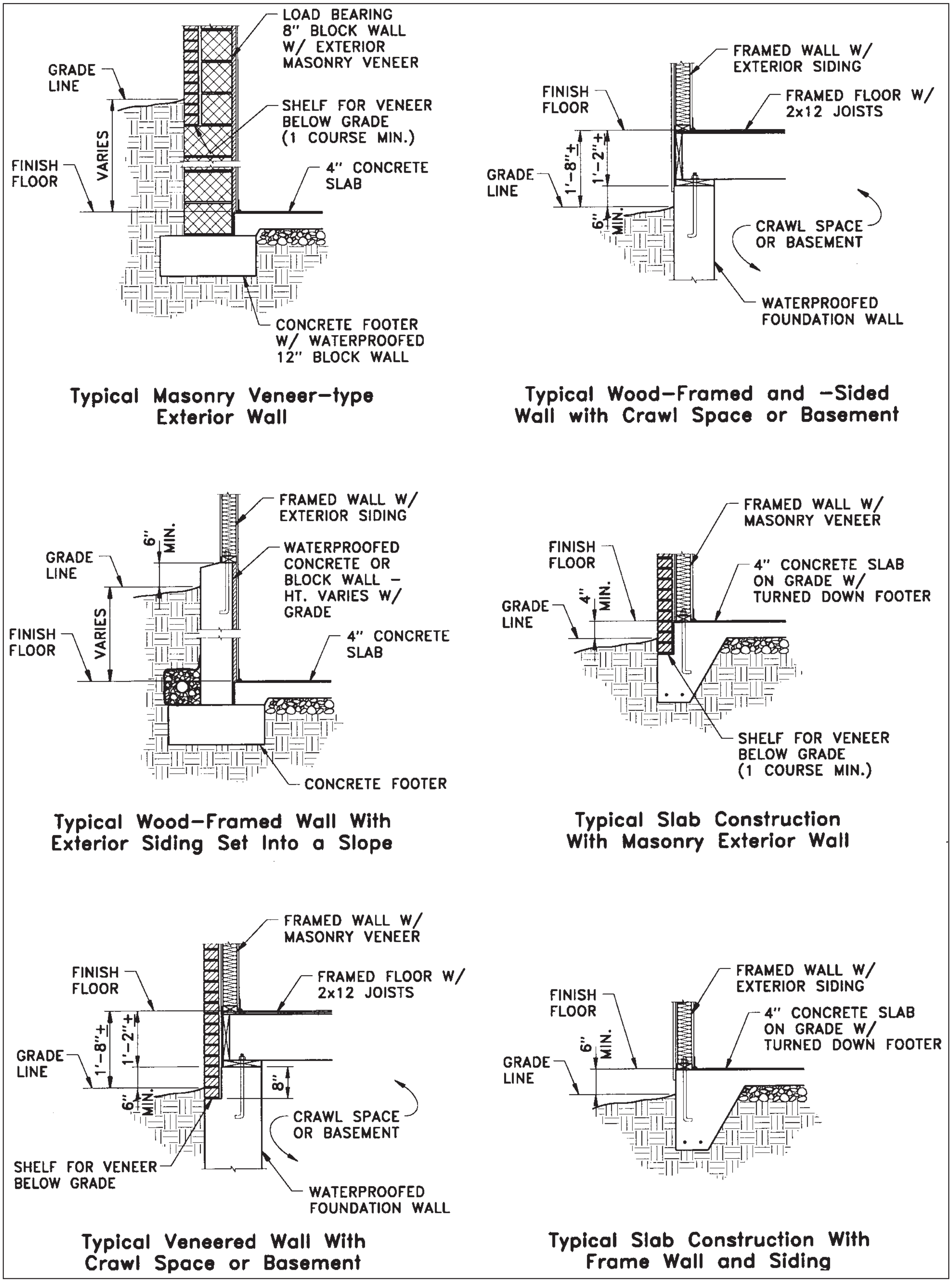


FIGURE 23.21 Foundation systems. (Reprinted with permission of Harris, C. and N. Dines. 1988. *Time Saver Standards for Landscape Architecture.* New York: McGraw-Hill)

the depth of topsoil that will be spread on the lot. Draw the second (referred to as the *0.5 contour*) midway between the 0.0 contour and the house footprint. At this location, the fill depth will be equal to one-half the difference between the considered drop (at the unit) and the 0.5-foot assumed drop at the 0.0 contour. Draw the third (referred to as the *1.0 contour*) just outside the perimeter of the house footprint. At this location, the fill depth will be equal to the considered drop. Figure 23.22 illustrates the placement of the 0.0, 0.5, and 1.0 contours.

2. Measure the area within each contour. For the area of the 0.0 and the 0.5 contours, the entire internal area and not just the area from one contour to the next should be measured. However, the area of the basement footprint is excluded from each measurement because no fill will be spread in this location.

3. Use Equation 23.7 to calculate the required fill volume.

$$F_v = \left[\frac{1}{2} A_{0.0} + A_{0.5} + A_{1.0}\right] \cdot \mathrm{CI} \tag{23.7}$$

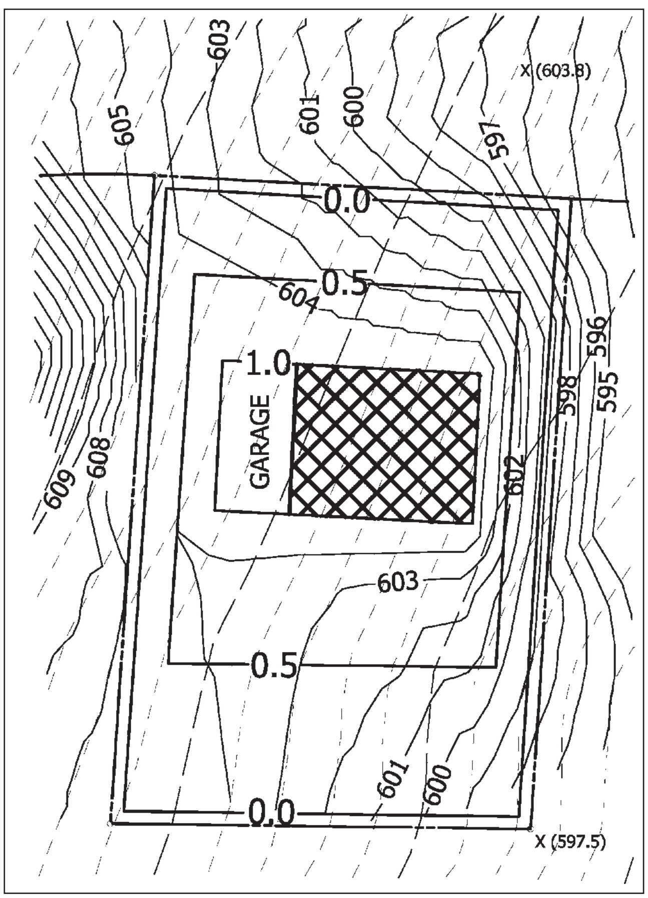


FIGURE 23.22 0.0, 0.5, and 1.0 contours for mass grading calculations.

TABLE 23.2 Contour Intervals for Mass Grade Calculations

DROP	CONTOUR INTERVAL (CI)
1.0	0.25
1.5	0.50
2.0	0.75
2.5	1.00

*Note: Both drop and contour interval have the same unit associated with them (e.g., a 1-foot drop has a 0.25-foot CI, etc.).

where F_v = required fill volume, $A_{0.0}$ = area inside the 0.0 contour (minus the area of the basement), $A_{0.5}$ = area inside the 0.5 contour (minus the area of the basement), $A_{1.0}$ = area inside the 1.0 contour (minus the area of the basement), and CI = contour interval, as shown in Table 23.2.

Grading in Commercial Sites

Commercial projects (e.g., high- and low-rise office, retail plazas, houses of worship, and schools) consist mainly of buildings, parking areas, and access points. Due to the high premium rates for commercial land, rarely are there large areas of natural ground to allow for extensive flexibility in the grading scheme. On residential projects, groups of lots are worked on simultaneously and the grading can extend beyond the limits of a single lot, since the group of lots has only one owner. On commercial projects, rarely does one owner develop several parcels simultaneously. Therefore, the limits of the grading cannot extend off-site. Grading on an adjacent parcel with a different owner requires permission in the form of a letter of agreement or an off-site grading easement, either of which can be difficult and expensive to obtain. Therefore, assume that proposed grades must tie out at the property line. When this practice requires expensive retaining walls or severely curtails the development program, then it is appropriate to explore the off-site permission. On small sites, this limitation makes developing a grading plan more challenging, especially when steep slopes exist.

Siting the Building and Other Structures. When siting the building(s) and any other structures on the property, one must position them in a manner that optimizes the area, promotes public safety, is harmonious with the adjacent properties, and ensures compliance with all appropriate codes and ordinances. In most cases the lot layout is created during preliminary design. Refer to Chapter 11 for a complete discussion on laying out a commercial property.

Type of Site. Each type of commercial development has its own features and needs associated with those features. The following items are examples of special grading needs based on the type of site:

- A fast-food restaurant might require the design of a drive-through facility, which would require that fairly steady grades are held around the building.
- Commercial developments usually have some type of Dumpster pad/enclosure located on the lot. Features such as Dumpsters are typically screened by means of landscaping. In some cases, aesthetic grading is used in conjunction with landscaping.
- Commercial sites, by nature of being public, have a certain amount of space that must maintain suitable grades to provide accessibility for disabled persons, according to the ADA Accessibility Guidelines. In cases such as senior living facilities, these areas may be wider and occur at more frequent intervals.

Property Lines and Setbacks. Siting the building parallel to at least one property line is usually the preferred method. To provide enough room for parking areas, it is common for the building to be situated as close to one or two of the property lines as possible. In general, required setbacks are applied to the building(s) and structures. However, some municipalities also have separate setback requirements for pavement such as parking lots. Setback requirements are typically determined in the preliminary design phase when the building is sited. The important thing to remember is to leave enough room between the property lines and the structures to allow the proposed grades around them to transition appropriately to meet the existing grades along the property boundary.

Grading the Site. The controlling factors for grading commercial sites are basically the same as for other sites and include drainage, slopes in parking and pedestrian areas, and access points to the building structures. From an aesthetic point of view, the grading concept for commercial sites is often tied to the visual goals the architect (and developer) set for the proposed building.

Drainage. As in residential developments, the topography of the lot plays a big part in laying out the lot. For example, the lot would be configured such that stormwater facilities would be located at a lower point of the property for ease of drainage. Further, it is desirable to have the building on higher ground. In general, the building elevation is set above the street.

Driveways and Access Road. The higher traffic volumes encountered at public entrances dictate more conservative guidelines than private driveways. A landing at least 20 feet long with a maximum slope of 4 percent should be provided at the entrance. Grades on-site should be in the 2 to 8 percent range. Local ordinances and requirements for access by physically disabled individuals (discussed later) must be incorporated into the plan.

Parking Lots. The necessity for large expanses of paving on commercial projects leads to rules of thumb somewhat unique to this genre. Remember the requirements for commercial entrances discussed previously. From the entrance, recommended pavement slopes in the travel lanes vary from 1 to 5 percent. The pavement is sloped to direct runoff to curb inlets, sump areas, or ditches off the edge of pavement. Placement of all drainage structures should take into consideration the movement of pedestrians and vehicles. Inlets should not be placed in areas of heavy pedestrian use, such as crosswalks and curb-cut ramps. Additionally, the designer should locate inlets in areas where people can access their vehicles without stepping around the inlet. Figure 23.23 shows recommended placement of inlets in parking areas.

Another rule of thumb is that long runs of sheet flow on steep slopes in parking areas should be avoided, especially in colder climates where the sheet flow can freeze and create hazardous conditions for pedestrians and drivers. Additionally, runoff should be directed away from sidewalks and pedestrian travelways, as this not only makes it easier for walking but also reduces the splash from passing traffic.

When devising the grading scheme in larger parking areas, consideration should also be given to paving operations. Parking areas that have extensive washboard effects are difficult to pave, especially if there are numerous grade breaks and relatively steep slopes.

Many commercial buildings have ramps that lead to underground parking or to loading areas. The grading should direct the runoff away from the ramp areas, while inlets at the bottom of the ramps carry the small amount of runoff that does fall in the ramp and loading area.

Utility Services. In the discussion of residential developments, it was noted that it is best to set the building elevation to provide for gravity drainage to an existing sanitary sewer. The same is true in commercial applications. This is because gravity drainage of the site's wastewater is the most economical solution.

Grading around the Building(s). The grades around the perimeter of a commercial building typically do not vary

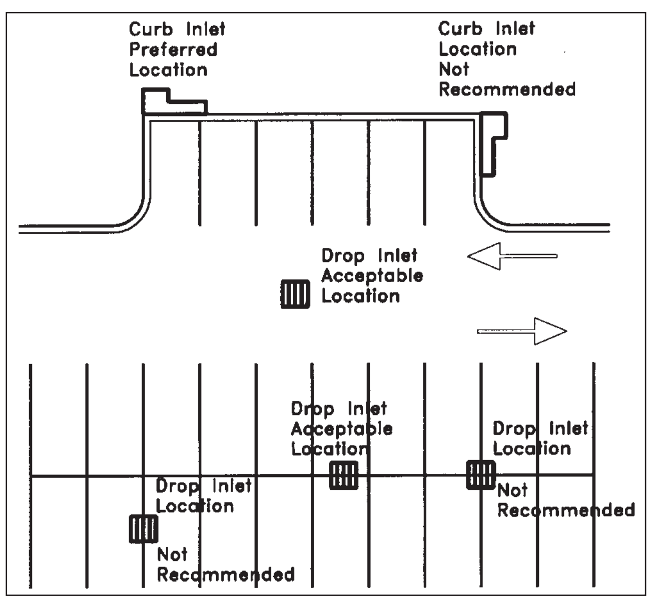


FIGURE 23.23 Recommended inlet locations.

unless the existing terrain has slopes that dictate it. Figure 23.24 illustrates a possible grading scenario around a commercial building. Following are examples of areas around the building that may require special grading:

- *Entrances:* In lieu of steps, walkways may be graded toward the building to meet the finished floor elevation.
- *Loading docks:* Pavement ramps (with possible walls) may need to be designed/graded to provide access to either raised or lowered entries to the building.
- *Drive-throughs:* Special care must be given when grading a drive-through where an access road has its edge of pavement/curb almost touching the face of the building. It is usually easy enough to grade away from the building. But it might be more difficult to grade the road to provide drainage, as it is constrained by the grades along the perimeter of the building.

GRADING AND DESIGN SOFTWARE

The process of grading as explained in this chapter has developed over many years; most of the concepts presented have been in use long before the advent of computers. These concepts change very little, and they must be thoroughly understood before trying to grade a site. Only when the designer has this understanding should electronic tools commonly offered through computer programs be employed.

Moreover, it should be remembered that, in many ways, grading is an art. Therefore, computers—no matter how sophisticated they become—will never be able to produce a grading plan better than a human being can. Computers should be considered a valuable grading tool but not a substitute for the designer's experience and skill.

Smart Drawings

Computer-aided design (CAD) software, such as AutoCAD by Autodesk, Inc., and MicroStation by Bentley Systems,

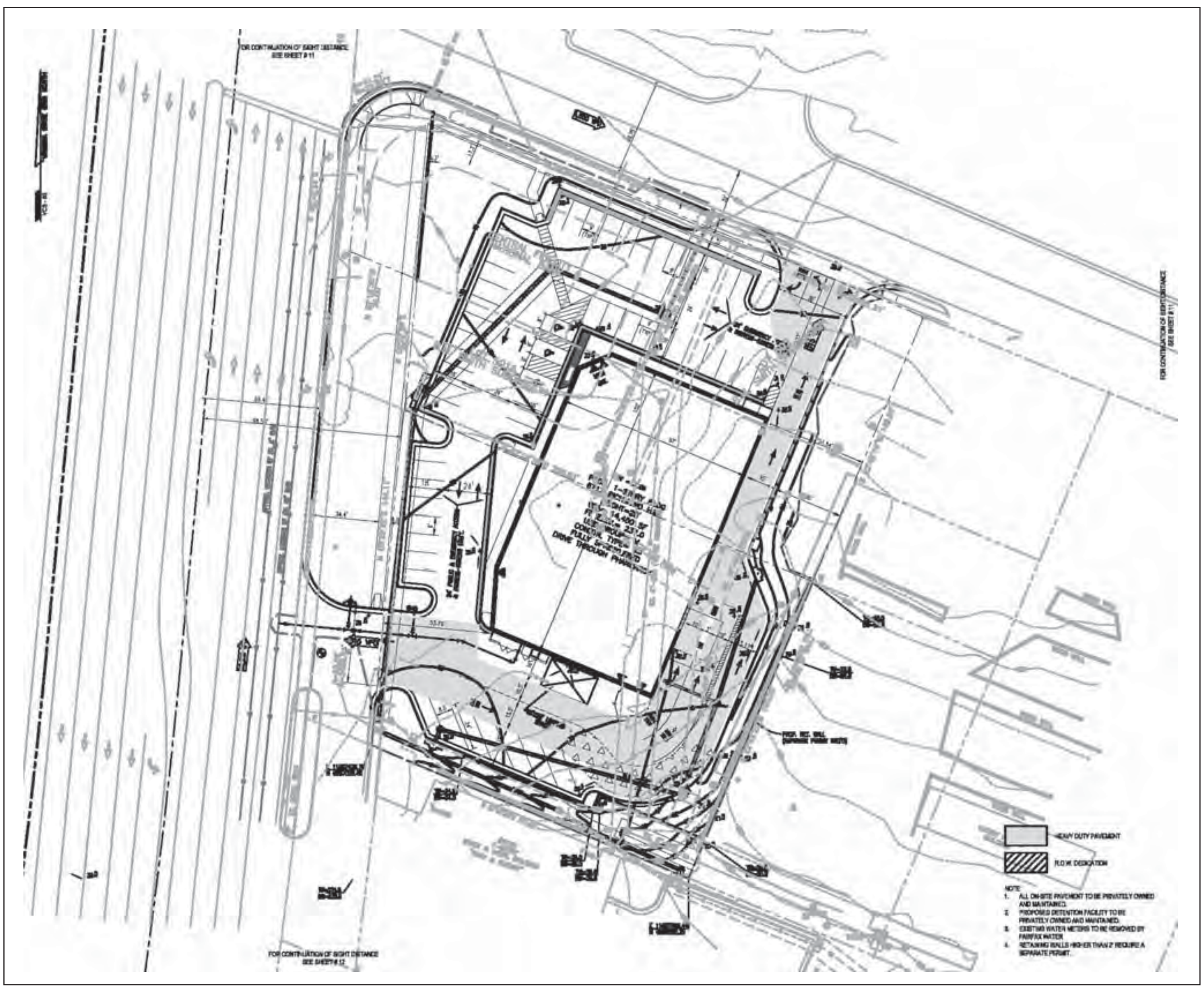


FIGURE 23.24 Commercial building grading plan.

Inc.—typically used for the drafting of maps and engineering or architectural drawings—can also create three-dimensional models (or designs). CAD files of this nature are referred to as *smart drawings.* The drawing is considered smart because it has more data information than a typical flat (two-dimensional) drawing. With traditional flat drawing, two or three drawings (or views) may be required to convey all the necessary dimensions. One smart drawing has within it all the dimensions.

Digital Terrain Models

Description. A digital terrain model (DTM) is a database of points that each have three spatial coordinates (*x, y,* and *z*). These points are connected to form a series of adjacent triangles representing an irregular surface. Figure 23.25 is an example of a DTM.

As discussed in Chapter 14, survey points are compiled to create a DTM of the existing ground surface. This DTM is then used to generate the existing contours using one of the surface modeling software packages. By creating a proposed DTM (proposed surface), proposed contours can be similarly generated. This eliminates the tedious task of hand-drawing contours after interpolating their configurations based on spot elevation locations and intended drainage patterns.

Creating the Proposed Surfaces

Land development design software such as Land Desktop by Autodesk, Inc., and Inroads by Bentley Systems, Inc., has automated most of the more mundane tasks associated with grading. Further, as the software becomes more sophisticated, it is becoming more capable of actually designing the entire proposed surface (grading plan). However, the

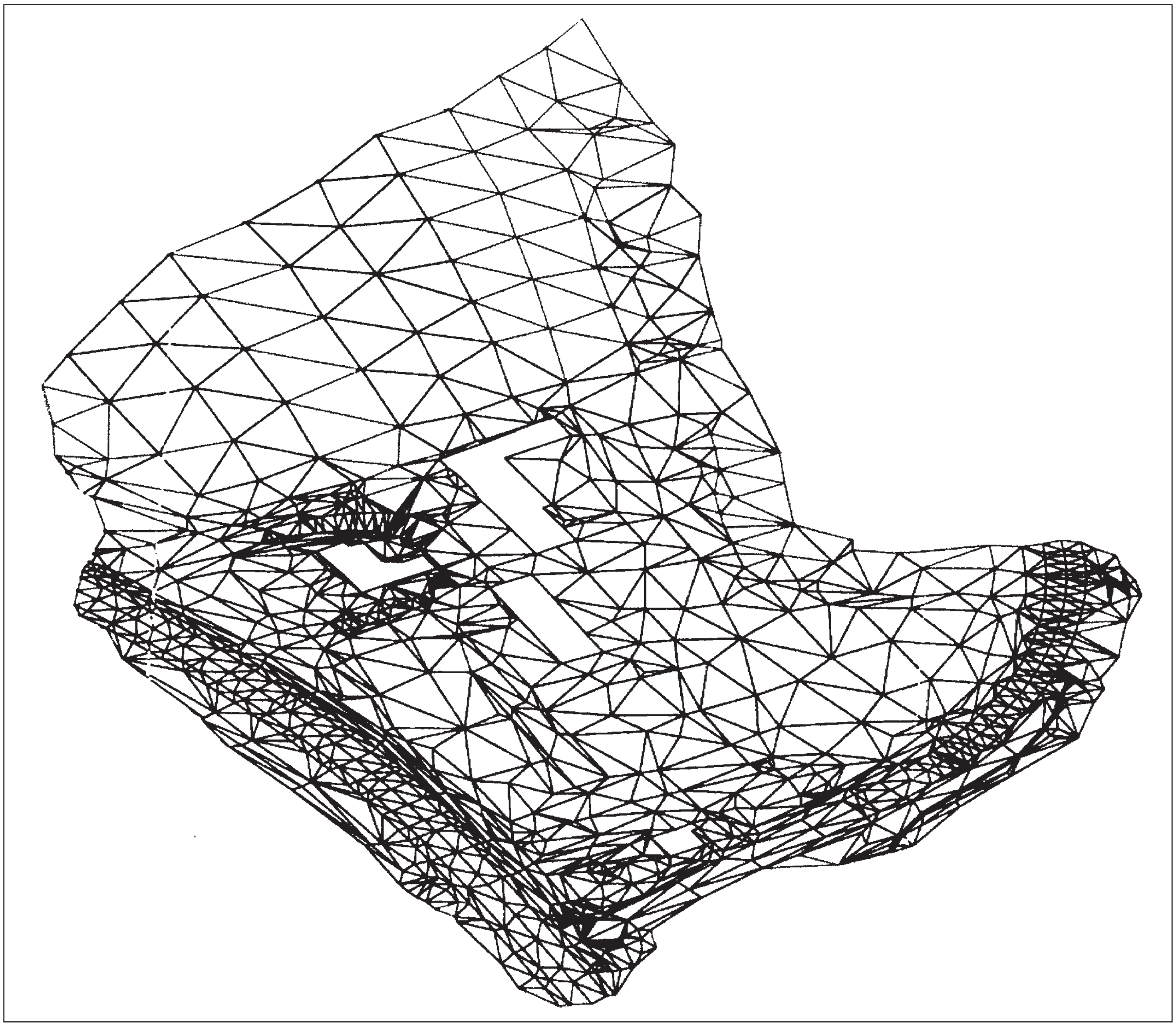


FIGURE 23.25 Digital terrain model (DTM).

designer should be knowledgeable of the principles presented in this chapter. As a rule of thumb for using any design software, the designer needs to understand and know what information to give the computer and be knowledgeable enough about the subject to validate and use the information the computer returns.

There is an array of specific grading tools being developed within the different surface-modeling software packages to model roadways, ponds, berms, parking areas, and so on. However, there are basically only three types of information contained in a smart drawing that is input into a DTM to define the proposed surface:

1. *Random points:* A single point would be input directly into the DTM to define such things as the high point of a hill, the low point of a pond, or the top of a drainage inlet.

2. *Breaklines:* Breaklines are lines that reside in three-dimensional space. They represent continuous, defined edges such as top of ridge, bottom of swale, crest of road, face of building (at ground surface), or walls. Grading tools used to model roadways and parking areas typically generate a set of breaklines, commonly centerline or profile grade line (PGL) as well as top of curb and flow line, that define the features.

3. *Contours:* Contours are three-dimensional lines; the z-coordinate (elevation) is equal for all combinations of x and y. Contours are input into the DTM to define such things as berms and ponds or to define any area that cannot be adequately defined by random points and break lines.

Using Smart Drawings and DTMs for Construction

Smart Drawings and DTMs in the Field. As technology has advanced, contractors have acquired the ability to input digital information into their equipment to facilitate the construction of a site. Considering this, two questions come to mind: What information is needed for machine-controlled grading and who will be responsible for supplying this information?

For the most part, the proposed grading plan itself does not provide a contractor sufficient information to grade a site. This is mainly because it typically reflects only finished grades. The contractor, however, is interested in the mass grade configuration as well as finished grades. The designer must remember that the contractor first mass grades the site in order to install roads, utilities, foundations, and so on. Therefore, information about road boxes, trench configuration, basement depth, subbases, and so on, are the main concern for initial construction of the site. The contractor must use profiles and details included in the plan set in addition to the grading plan. This situation would remain the same if a smart drawing of the grading plan were sent to the contractor. Following this same logic, the proposed surface (DTM) would also be insufficient.

Now a mass grade surface could be prepared. A mass grade surface DTM would not only provide a contractor with all the required mass grading information in one place but could also be used by the designer to better estimate earthwork quantities. So should the designer make it a practice to prepare full mass grade DTMs? To answer this, the designer must decide whether the additional work justifies slightly more accurate earthwork calculations. Further, consideration should be given to whether the designer prefers to reduce (or eliminate) the responsibility of the contractor to compile the needed mass grade information from the plans, profiles, and details by providing this information in a mass grade DTM. This in itself might justify the extra work. However, a good contractor will most likely still take the time to check the DTM against the plans, profiles, and details.

Long before the age of machine control, contractors used the designer's drawings to construct a site. Machine control is a valuable tool for the contractor. However, it does not change the design and/or construction concepts presented in this book. A set of site drawings provides all the information required to construct the site. The process of the contractor—extracting the information from the plans—has always acted as a check of the information. So it may make the most sense to leave machine control considerations to the contractor.

Feasibility and Liability. One of the most common and dangerous mistakes is to believe that computers are infallible. It is very easy to believe that all the information contained in a smart drawing is accurate. It is important to remember that much of the information in the smart drawing for the proposed conditions was created by the designer and not by the computer. It is very possible that what is printed is different from what is found by inspection of the three-dimensional model. A proposed DTM is an approximate representation of the surface that is to be constructed. It is defined by the amount of information it contains. The more information (points) provided, the closer the approximation is. Consideration must be given to whether or not a DTM contains adequate information to be used for construction before providing it to a contractor.

However, on cooperative project construction where the engineer and contractor work together, commonly referred to as design-build delivery, the need for the engineer to provide higher-quality information is certain. Although this design-build is more common for transportation and large-scale infrastructure projects, it is becoming increasingly common in the land development field as well, especially for public-sector clients. Client cost savings have been shown on projects where the contractor is included in the design process to check and validate construction techniques for earthwork balancing that account for bulking and shrinkage of materials typical for the area to be constructed. The contractor's knowledge, if leveraged in the design process, can significantly improve the cost savings to the client and the speed to complete the project.

GRADING SUMMARY

The person designing the site grading plan must combine several skills to accomplish the task. Knowledge of plan graphics and the mechanics of grading provides the means to represent the scheme on paper. Identifying the natural and manmade constraints and knowing how to work with them ensures feasibility. Manipulating the grades so that the proposed uses are facilitated and enhanced contributes to the plan's viability. Creation of an attractive site that is enhanced by the grading helps marketability. Accomplishing all of this requires a combination of art and science rarely equaled in any other aspect of the site development process.

EARTHWORK INTRODUCTION

The term *earthwork* refers to the manual movement of soil. Earth is taken from one location and moved to another in order to form the land as desired. In general, moving earth from one location on a site to another can be expensive. It is even more costly to a project when earth must be removed from or brought onto a site. Therefore, it is very important to have a balanced site, where there is not a large amount of excess soil or, conversely, soil demand.

CUT/FILL MAPS

The term *cut* refers to an area where soil is removed, while the term *fill* refers to the area where soil is added. Additionally, *excavation* refers to the removal of soil and material from an area, and *embankment* is used to reference the addition of soil onto an area to bring it to grade. For example, a cut area is evident by the upward sloping ground along the sides of a road, while fill areas are evidenced by the downward slopes away from a building or street.

Cut and fill areas are indicated on the grading plan by comparing the existing contour lines to the proposed contour lines at a specific location. Where the proposed contour line elevation is higher than the existing contour line elevation, the area is a fill. Conversely, a cut area is one in which the proposed elevation is lower than the existing elevation.

Figure 23.26 shows a grading plan of a building with cut and fill areas. As an example of determining the depth of cut from comparison of contour lines, consider point A, where the existing 106 contour line intersects the proposed 100 contour line. The section view shows the 6-foot depth of cut at this point.

The left side of the building is a cut area and the right side is a fill area. The plan view shows a line around the cut and fill areas known as the *zero cut/fill line*. This line connects the points where no fill or cut occurs and separates the cut areas from the fill areas. Additionally, notice that the line also follows the points where the proposed contour lines connect to the existing contour lines around the perimeter of the graded area. Since the basement floor elevation has been established at elevation 99.0 feet, the zero line follows the existing 99.0 foot contour line through the center of the building. Although this grading plan shows only one cut and one fill area, other projects may have several areas of both types. The zero cut/fill lines are helpful for determining earthwork quantities, which will be discussed later in this chapter.

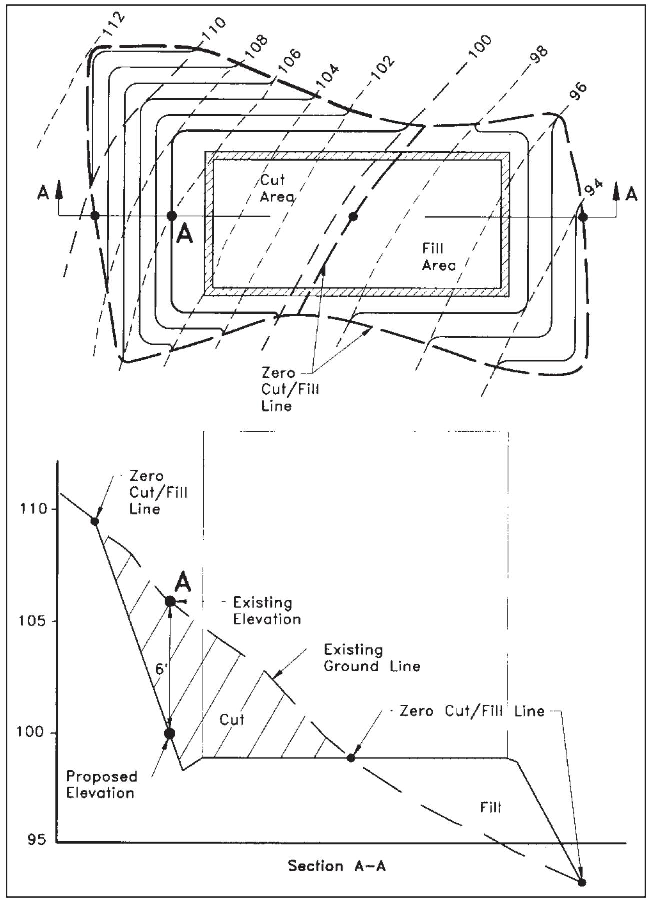


FIGURE 23.26 Plan and section view showing cut and fill areas.

Consideration of cut and fill quantities is very important when developing a grading plan. For many reasons, a balance of cut and fill is usually desirable. Balance is achieved when the quantity of cut is roughly equal to the amount of fill. For example, in order to create a flat area on a hillside, it is most effective to cut into the hillside and use the excess soil as fill on the lower portion of the site. This concept is illustrated in Figure 23.26.

One of the most compelling reasons to achieve a balance of earthwork is its effect on project cost. Moving soil around a site is less costly than either importing fill to the site or hauling excess cut from the site. Generally, importing fill onto the site costs more than hauling excess material away. Balancing the earthwork helps keep costs under control and often will help the finished site appear more in harmony with its surroundings.

The relationship between cut and fill is simple in concept, but other factors must be considered that complicate the equation. These factors include:

- Construction qualities of the specific soils on site. It cannot be assumed that on-site material may be used as fill, especially in areas where a load, such as a building or wall, is to be placed. The designer must verify the engineering characteristics of on-site soils rather than assume they may be used as fill material. (See Appendix C for further discussion.)

- Soils generally shrink when used as fill, and the shrinkage factor can vary greatly between different soils. A grading plan that appears to produce a balance of materials may come up short on fill due to the shrinkage of the fill volume.
- A site developer may have several concurrent projects with different cut and fill needs. It may be desirable to intentionally produce a need for fill on one project in order to dispose of excess fill from another nearby project (hauling fill long distances is impractical due to high costs).

EARTHWORK

Calculating the amount of displaced material is referred to as an *earth takeoff* (ETO). Although rarely the case, the ideal scenario is to have a balance of earthwork, where all of the required excavation is used to backfill and to bring the lot to finished grade. In order to attain any semblance of an earthwork balance, the excavated material must be of adequate quality to be reusable. In projects with excessive rock, loam soils, or expansive soils, an earthwork balance, in all likelihood, is unattainable. If a balance cannot be attained, the next best alternative is to have excess soil, since hauling the excess away from the site is typically less expensive than hauling in borrow material.

A grading plan may have to go through several iterations before an acceptable earthwork balance is obtained. Frequently, a rough grading plan is developed as a first approximation during preliminary engineering. This rough grading plan shows the buildings, streets, and parking areas with spot elevations at critical points and contour lines with 2-foot or 5-foot contour intervals. An ETO is performed to determine the net earthwork quantity. Since this rough grading plan serves as an unpolished first guess for design, the earthwork analysis cannot be extraordinarily detailed. As the rough grading plan is refined and approaches final design, the detail and accuracy of the earthwork analysis increases.

Most earthwork calculations are performed with the aid of earthwork software, although occasion does arise when manual methods are either more effective or required because it is too early in the design process for electronic files to have been created. Of the several methods presented herein, the one selected depends on the type of site and the way the project is set up. For many projects, the ETO is developed from the contour grading plan or, in the case of roads, the cross-section drawings. Of major interest to the developer or contractor is the net amount of cut and fill material. Therefore, in order to get a final quantity, cut and fill values must be adjusted for such things as topsoil, pavement thicknesses, undercut, large conduits, soil shrink-swell, and other factors.

ETO METHODS

Cross-Section Method

The cross-section method is used to calculate earthwork quantities for roads, utility trenching, and other projects when the length is greater than the width. A contour grading plan is not necessarily needed to use this method, since cross sections for streets and prismatic channels can be obtained from the typical section and the profile. Street cross sections are easily plotted manually, although computer software is available to easily produce street cross sections.

If the cross-section method is used for a building site, the grading plan is used to develop the cross sections. A baseline or reference line is drawn on the plan. Although the location is arbitrary, it is usually down the center or along one edge of the project. The baseline does not need to be straight. Slight curvature or angles can be used when the situation warrants. Lines perpendicular or radial to the baseline are drawn where the cross sections are desired, and the sections are then plotted. Distortion of the topography as it appears on the cross-section plot increases when the section line is significantly skewed relative to the prevailing land slope; this contributes to errors in the cut and fill values. On the other hand, the distance is not uniform between two section lines if they are not perpendicular to the baseline, which also adds to the error in the ETO. Judgment and experience dictate the orientation of the section line relative to the baseline and prevailing land slope in order to obtain reasonably precise ETO quantities.

Section lines do not have to be at constant intervals. They are located where the cut and fill does not substantially change and at points where there is an abrupt change between cut and fill. For example, cross sections located before and after foundation walls will not account for the excavated volume. Additional cross sections should be included just inside of the foundation walls. Precision of the ETO depends on judicious selection of the cross-section location and their orientation to the baseline.

Once the existing and proposed grades are plotted on the cross sections, thicknesses for pavement, concrete slabs, and subbase depths are then added to the drawings. The gross cut and fill quantities are adjusted according to these depths. The cut and fill areas of each section are determined by using a planimeter, geometry, or grids. The last way is tedious and has inherent errors (e.g., estimating partial segments of the squares), but can be effective for very rough estimates. If the measured area from the cross-section drawing is in square inches, the conversion to actual square feet based on the horizontal and vertical scale is:

$$SF_{act} = A \cdot H_{scale} \cdot V_{scale} \tag{23.8}$$

where SF_{act} = actual square feet, A = measured area in square inches, H_{scale} = horizontal scale in feet per inch, and V_{scale} = vertical scale, also in feet per inch.

$$V_{inc} = \frac{A_i + A_{i+1}}{2} \cdot L \tag{23.9}$$

The incremental volume of cut and fill between successive cross sections is equal to the averaged area of the cut or fill multiplied by the (average) length between the cross sections, as given in Equation 23.9, where V_{inc} is the incremental volume of material between two consecutive cross sections, A_i and A_{i+1} are the areas of cut or fill on the two consecutive cross sections, and L is the average horizontal distance between the sections. Summation of the incremental cut and fill volumes determines the total cut and fill volumes for the site.

The volume from the average end area (Equation 23.9) significantly overestimates the volume at the two end sections. As shown in Figure 23.27, the solid segment L is wedge shaped. The volume for a wedge (pyramid) is:

$$V_W = \frac{A}{3} \cdot L \tag{23.10}$$

where A is the area of the first cross section, in this case station A_i. A comparison of the volumes for the wedge segment as computed by the average end area and the wedge equation shows that the average end area volume is 50 percent greater. The volume resulting from this error in this segment must be weighed against the total volume of earthwork. Since the error applies only to the two end segments, it is left to the judgment of the engineer which equation is used for the wedge-shaped segments.

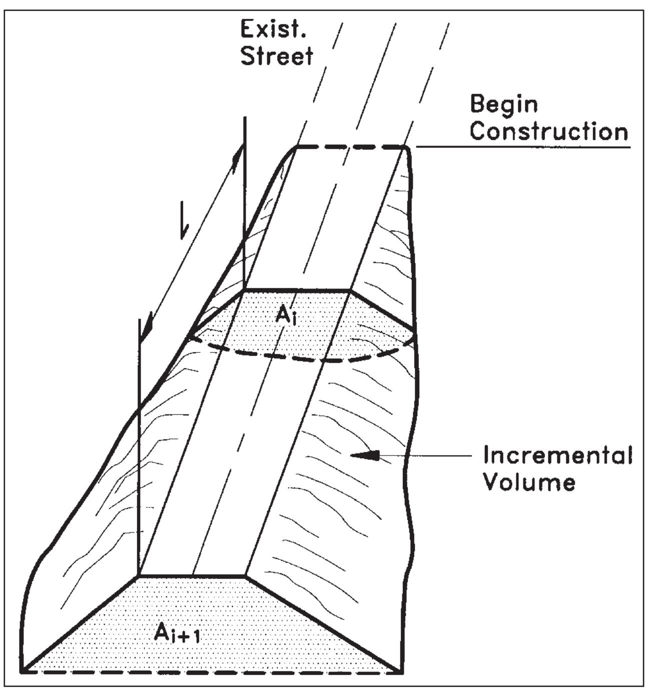


FIGURE 23.27 Wedge-shaped volume.

EXAMPLE 1

Figure 23.28 shows three cross sections of a roadway where C and F designate the cut or fill area on the cross section. Table 23.3 shows the tabular organization of the data to determine the earthwork quantities using the cross-section method. (Assume stations 0+50 and 2+50 are the begin and end points of construction.)

The accuracy of this method is determined by the variation of cut or fill areas of subsequent cross sections. Although most cross sections are taken at constant intervals, intermediate cross sections may be necessary. If one cross section is in total fill and the following cross section is in total cut, an intermediate cross section is necessary for a higher degree of accuracy. The intermediate cross section is located where the fill section transitions to the cut section, the point where the cut and fill areas are nearly zero. The accuracy of this method can be increased if the interval length is reduced. The trade-off for this increased accuracy is the time to evaluate more cross sections. Another factor affecting accuracy is the cost for cut and fill. An extremely high cost associated with the cut or fill operations necessitates that the computed earthwork quantity be considerably more accurate. Consideration for additional cross sections through a curve is necessary

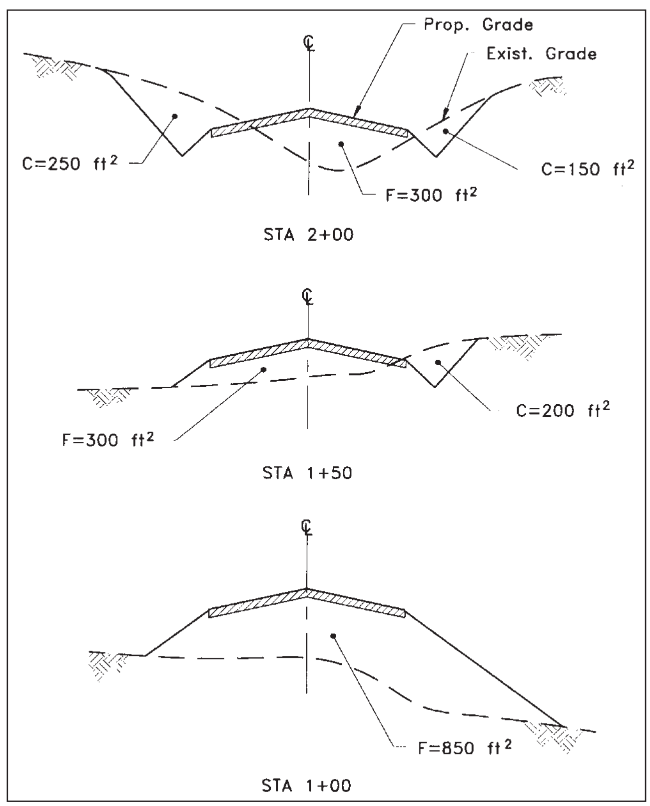


FIGURE 23.28 Earthwork example: Cross-section method.

TABLE 23.3 ETO by Cross-Section Method

(1) STATION	(2) LENGTH (FT)	(3) AREA (FT^2)	(4) AVERAGE AREA (FT^2)	(5) INCR. VOLUME (FT^3)	(6) ACCUM. VOLUME (FT^3)
			FILL		
0 + 50		0			0
	50		425	21,250	
1 + 00		850			21,250
	50		575	28,750	
1 + 50		300			50,000
	50		300	15,000	
2 + 00		300			65,000
	50		150	7500	
2 + 50		0			72,500
			CUT		
0 + 50		0			0
	50		0	0	
1 + 00		0			0
	50		100	5000	
1 + 50		200			5000
	50		600	15,000	

Column 1: STATION—the stationing along the street that identifies the location of the cross section.
Column 2: LENGTH—the length between the two cross sections. Notice this value is written on a line between the two cross sections of column 1.
Column 3: AREA—the total area of the cut or fill for the section. The first and last stations are the stations where the grading begins and ends. Here the cut and fill areas are zero.
Column 4: AVERAGE AREA—the average of the cut or fill area as determined by Equation 23.9.
Column 5: INCR. VOLUME—the volume of cut or fill between the two cross sections. This is equal to column 2 × column 4.
Column 6: ACCUM. VOLUME—the accumulated volume of cut or fill. Equal to the preceding value of column 6 added to the current value of column 5. The last value in this column is the total cut or fill for the total number of cross sections.

if the length parameter is longer than the arc length of the curve. In general, the average-end-area equation tends to overestimate volumes.

A variation of the average-end-area method considers the average of the areas within a closed contour loop. The average area is multiplied by the difference in elevation between the contour lines to obtain a volume. This method is best suited for computing volumes of lakes and mounds.

Contour Method

The contour method requires a contour grading plan. The amount of cut or fill material is determined by averaging the change in areas due to grading on two successive horizontal planes. This area is contained within the loop of the existing contour line and the proposed contour line. This averaged area is multiplied by the distance between the two plane areas to obtain a volume. To illustrate this point, Figure 23.29*a* shows a portion of a contour grading plan where the graded area is in cut. Figure 23.29*b* shows the change in plane areas resulting from the new grading. Each area is bounded by a loop composed of the existing contour line and the proposed contour line.

In Figure 23.30, the lines BCDE and B′C′D′E′ are the existing contour lines representing the two planes. Lines OP and O′P′ are the proposed contour lines on each plane. The change in surface areas from the existing to the proposed conditions are the loops OPDC and O′P′D′C′, which enclose areas A_1 and A_2, respectively. The volume of material is the

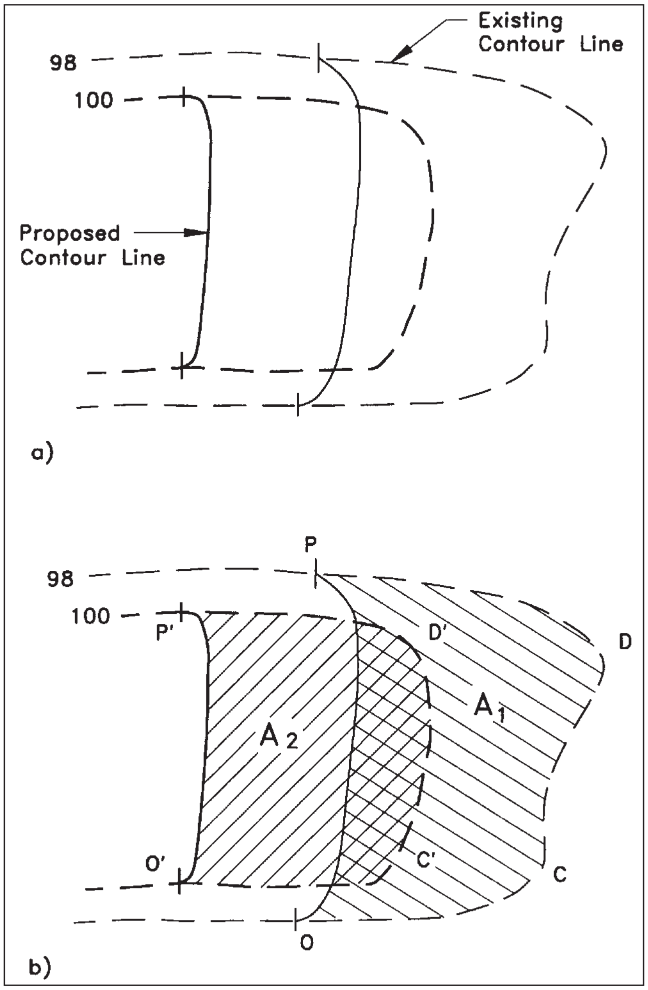


FIGURE 23.29 Contour grading plan illustrating change in areas.

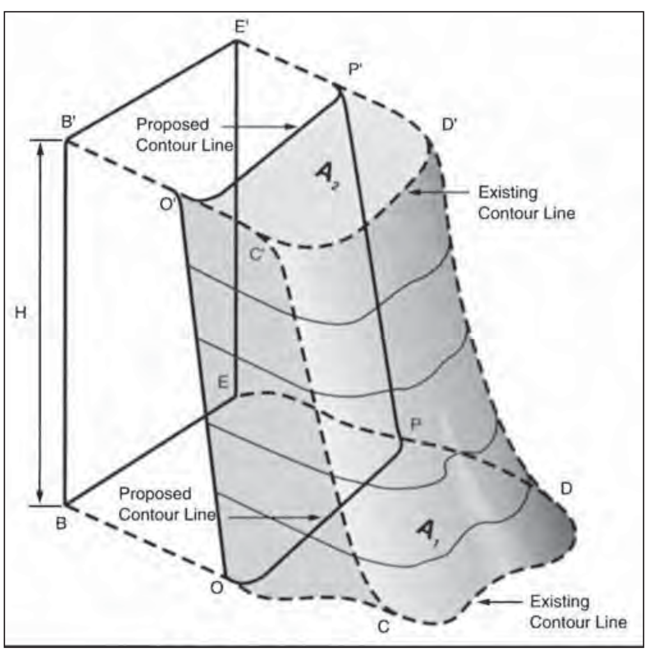


FIGURE 23.30 3-D representation.

prism of material between the horizontal planes of A_1 and A_2 and the inclined surfaces of O′P′PO and C′D′DC. This volume V is given as:

$$V = \frac{A_1 + A_2}{2} \cdot H \qquad (23.11)$$

The procedure for performing an ETO using the contour method is:

1. Delineate on the grading plan the limits of the cut areas and fill areas. These limits are identified by a closed loop that connects the points where proposed contour lines connect to the existing contour lines, essentially where the cut and fill is zero. These loops are identified as the zero loops, and the number of zero loops depends on the grading scheme. All grading within a zero loop is either all cut or all fill. All lines on the drawing representing zero loops should be drawn the same color. On the plan view, these points are indicated where the proposed contour line ties into the existing contour line or where a cut area changes to a fill area. In Figure 23.31, points A and C are where the proposed contour lines tie into the existing contour lines. Point B is where the cut area changes to a fill area. The zero lines are indicated in the plan view of Figure 24.31.

2. For each contour line within a zero loop, there are other loops composed of part of an existing contour and a proposed contour. Each of these loops outlines the change in area between the existing and proposed conditions for that contour plane. On projects where extensive grading is required, the loops will overlap, as shown in Figure 23.32. The basic procedure for delineating a loop is as follows: (a) on the grading plan (Figure 23.33) find where the proposed contour line meets the existing contour line; (b) from this point, using a colored pencil, trace the proposed contour line to the point where it joins the existing contour again; (c) then trace the existing contour line back to the original point; (d) do this for each contour within the zero loop; (e) identify individual loops with lines of alternating colors, which helps when tracing the planimeter around the loop. If a loop cannot be completely closed—that is, the proposed contour does not meet the existing contour within the bounds of the zero line—the zero line is not drawn correctly.

3. The incremental volume is the averaged areas of the two loops multiplied by the difference in elevation between the two contour lines.

After all loops have been outlined, the area of each loop is determined for each cut and fill area. After all loop areas have been determined and compiled into tabular format (see Tables 23.4 and 23.5), the table is completed by following through with the calculations of each column. If one table is used for each cut and fill area, a quick inspection of the tables identifies areas of the site where adjustments can be made to balance the cut and fill.

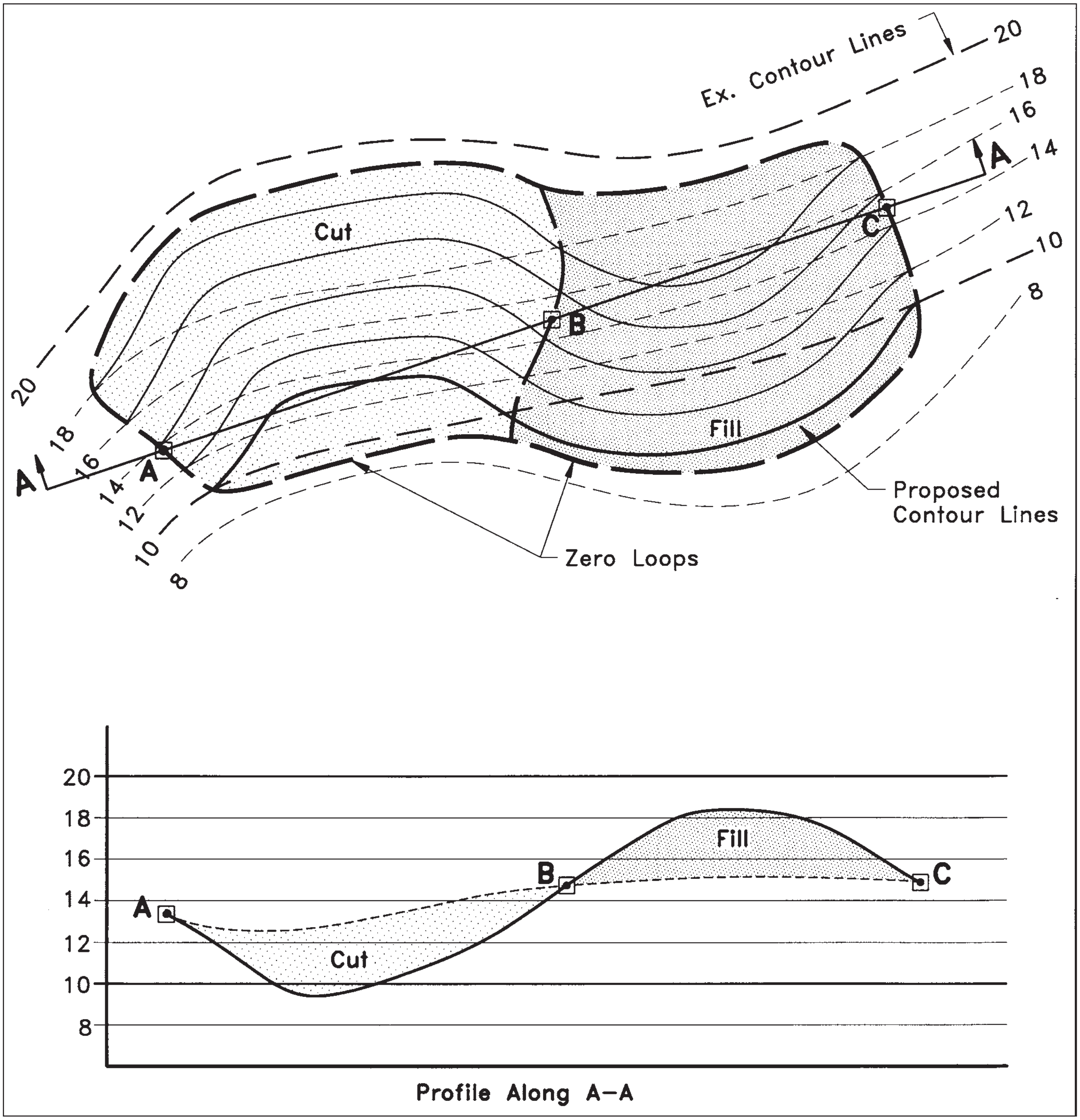


FIGURE 23.31 Schematic diagram showing zero lines.

EXAMPLE 2

Use the contour method to determine the amount of cut and fill for the grading plan of Figure 23.33.

The first step in the procedure is to determine the zero lines. For the grading plan example, some of these points along the zero line where the proposed contour lines tie into the existing contour lines are shown as points A, B, C, D, E, and F in Figure 23.32. The line C-G-H-D separates the fill area from the cut area. It is analogous to the line in Figure 23.31 that runs through the center of the graded area to divide the cut and fill areas.

Figure 23.34 shows the change in graded areas for the contour lines for elevations 414 feet, 416 feet, and 418 feet within the zero line for the fill area. For example, beginning at point J, a loop is made that follows the proposed contour line to point K, then

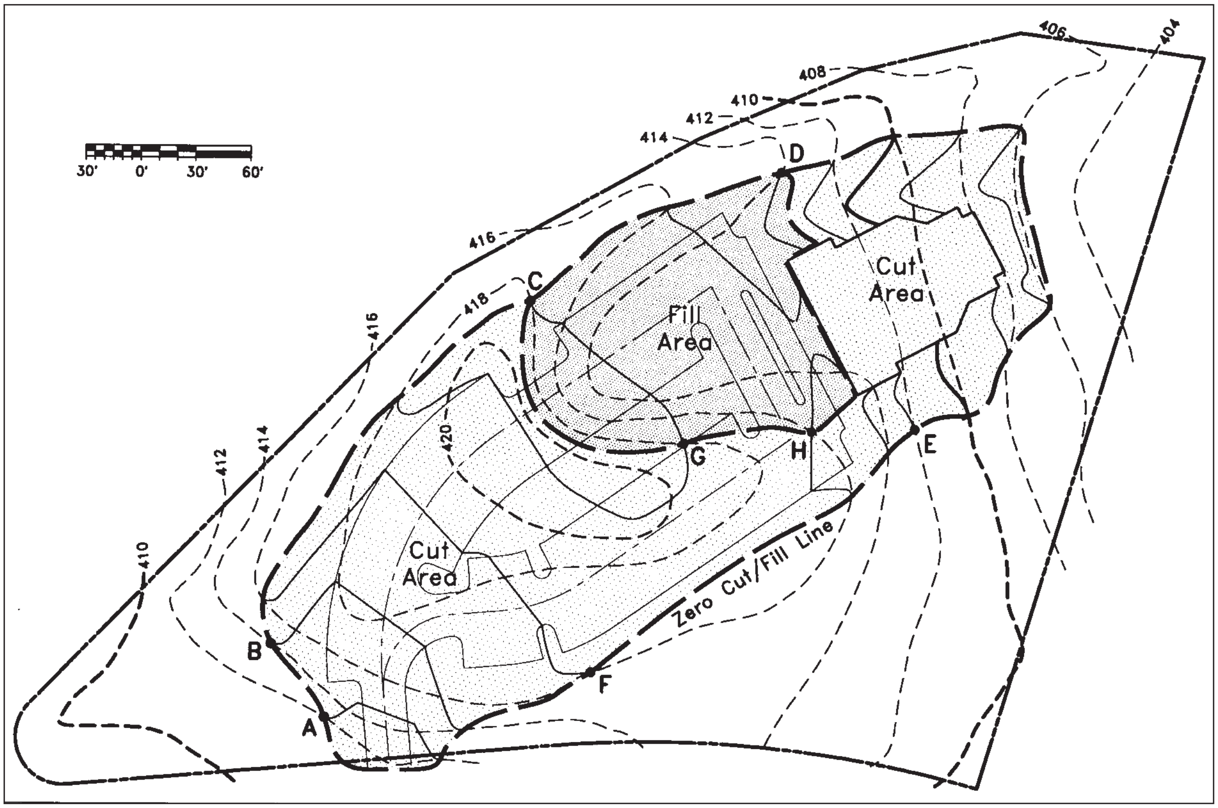


FIGURE 23.32 Grading plan showing cut/fill areas.

along the existing contour back to point J. Similarly, the areas for the loops MQM and NOPN are measured.

The loop areas for each contour line in the fill areas are measured and entered into a computation table (Column 2), as shown in Table 23.4. The following calculations complete the table.

Column 3: The average area for the first two consecutive contour lines—that is, for the 413-foot and 414-foot contour lines—is:

TABLE 23.4 Contour Method: ETO for Fill Area

(1) Elev. (ft)	(2) Loop Area (ft^2)	(3) Avg. Area (ft^2)	(4) Diff. in Elev. (ft^2)	(5) Incr. Vol. (ft^3)	(6) Accum. Vol. (ft^3)
413	0				0
		2714	1	2714	
414	5428				2714
		7348	2	14,696	
416	9268				17,410
		5529	2	11,058	
418	1789				28,468
		895	1	1790	
419	0				30,258

TABLE 23.5 Contour Method: ETO Quantities for Cut Area

(1) ELEV. (FT)	(2) LOOP AREA (FT^2)	(3) AVG. AREA (FT^2)	(4) DIFF. IN ELEV. (FT^2)	(5) INCR. VOL. (FT^3)	(6) ACCUM. VOL. (FT^3)
			PARKING AREA		
411	0				0
		680	1	680	
412	1360				680
		2829	2	5658	
414	4298				6338
		8468	2	16,936	
416	12,638				23,274
		14,501	2	29,002	
418	16,364				52,276
		8182	1	8182	
419	0				60,458
			BUILDING AREA		
405.4	0				0
		324	0.6	194	
406	648				194
		4336	2	8672	
408	8024				8866
		7186	2	14,372	
410	6348				23,238
		5168	2	10,336	
412	3988				33,574
		2055	2	4110	
414	122				37,684
		61	0.4	24	
414.4	0				37,708

$$\frac{8823 + 11453}{2} = 10138 \text{ ft}^2 \tag{23.12}$$

Column 4: The incremental volume is the volume of material cut or filled corresponding to the two consecutive contour lines. It is the averaged area (Column 3) multiplied by the elevation difference between the two consecutive contour lines.

Column 5: The accumulated volume is the preceding incremental volume added to the current incremental volume.

$$2 \cdot (416 - 414) \cdot 10138 \text{ ft}^2 = 20276 \text{ ft}^3 \tag{23.13}$$

Similar loop areas are obtained for the contour lines within the zero loop of the two cut areas, as shown in

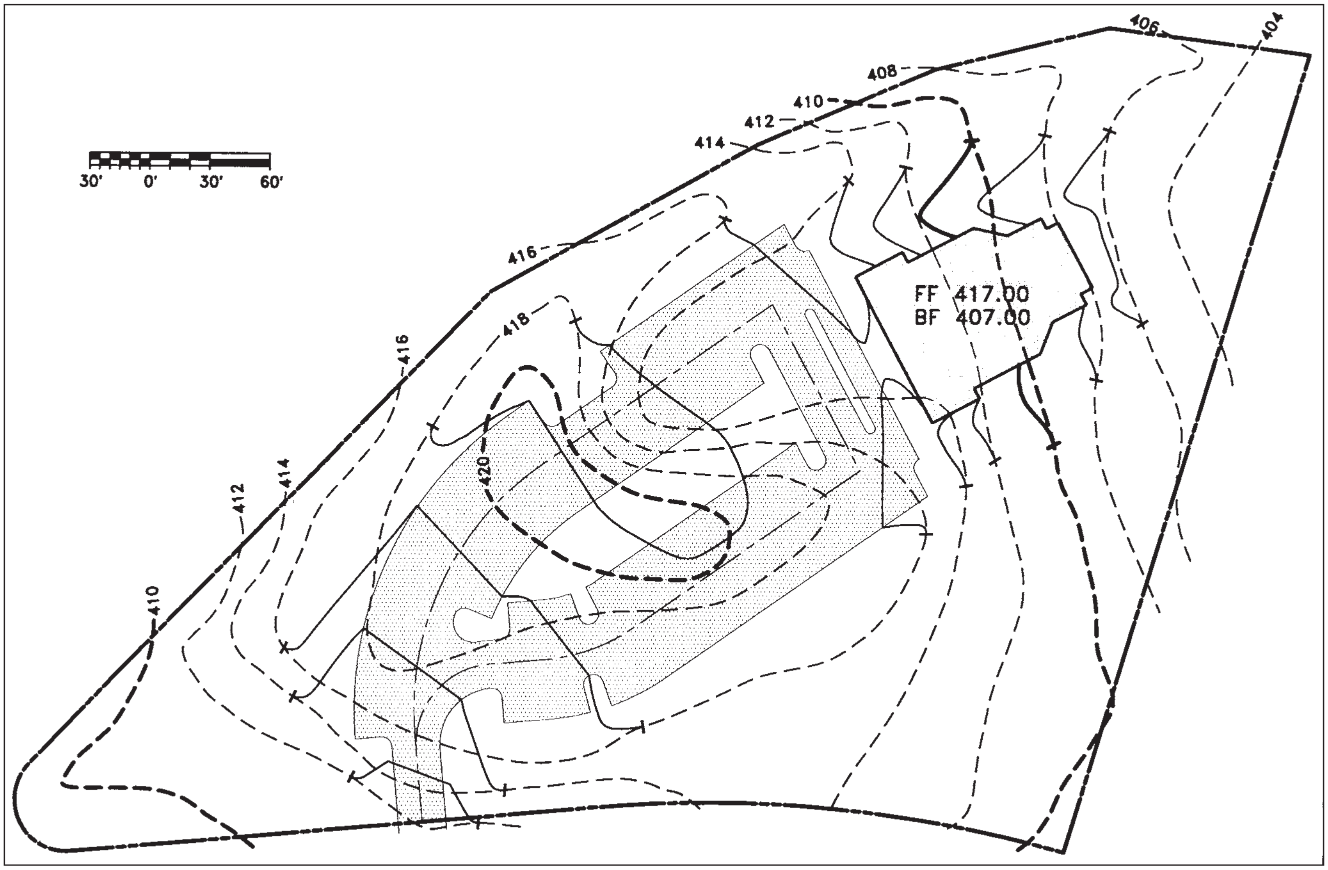


FIGURE 23.33 Grading plan.

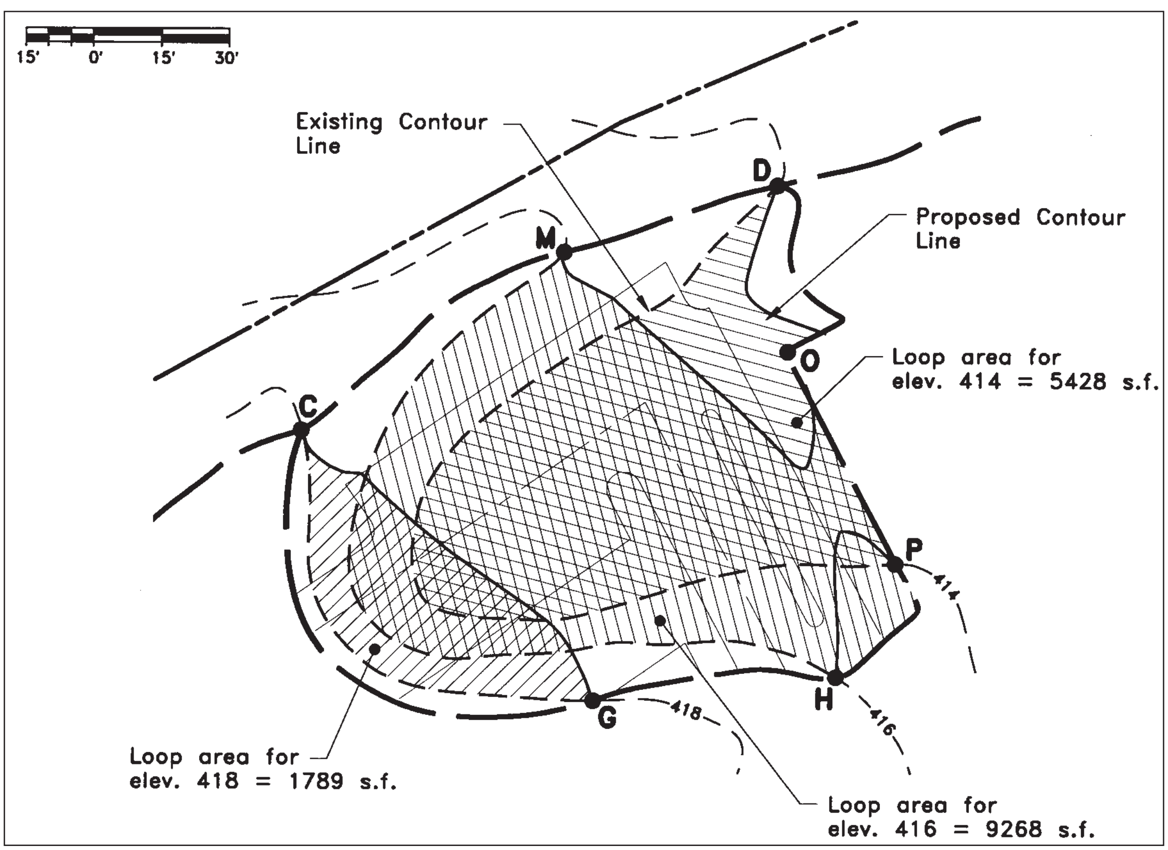


FIGURE 23.34 Contour method: loops for fill area.

Figure 23.32. One detail that must be pointed out involves the cut area around the building. A common error is to trace the building with the planimeter in the wrong direction. The path indicated as *ABCDEF* is the correct loop (see previous discussion on contour patterns for buildings and retaining walls in this chapter). The other loop areas around the building have not been shown for clarity. See Figure 23.35.

The total volume of material of cut and fill is:

$$\text{Total volume of cut} = \frac{(62556 + 38439)\ \text{ft}^3}{27\ \text{ft}^3\ \text{per yd}^3} \approx 3740\ \text{yd}^3$$

$$\text{Total volume of fill} = \frac{35662\ \text{ft}^3}{27\ \text{ft}^3\ \text{per yd}^3} \approx 1321\ \text{yd}^3 \qquad (23.14)$$

However, these volumes must be adjusted for topsoil, allowance for concrete and pavement thickness, and shrink and swell.

Equal Planes Method

Another method for estimating earthwork considers the volume based on averaging incremental depths of cut or fill. Each specific depth extends up or down from the proposed ground to the original ground line. The resulting configuration is a series of concentric, nested rings of uniform depths and variable widths. The height of each ring represents an incremental depth of cut or fill. The width of each ring represents the difference in area between two successive cut or fill contour lines. Whereas the contour and cross-section methods average the cut and fill areas on successive planes, the equal planes method averages the depths of cut or fill of successive rings.

To illustrate the incremental volumes of the equal planes method, consider an 8-foot-high mound built up from level ground. Imagine that the 8-foot elevation is represented by a ring of a specific radius, r8, as shown in Figure 23.36. The outer edge of the ring is formed by the 8-foot contour line. The volume of earth in this initial ring is that of a right circular cylinder = 8(pr82)/4. Next consider a ring formed by the 6-foot contour line with radius r6, (r6 > r8), concentric with the 8-foot-high cylinder. The incremental volume in this ring is 6p(d62 – d82)/4. Note that the volume between the ground line and the horizontal planes of the successive rings as shown in the triangle PQS of Figure 23.36 is not included in the calculations. This error is reduced by computing the incremental volumes by averaging the depths of fill (or cut) on two successive rings as indicated by triangles TUV and V′U′V′ on the left side of Figure 23.36.

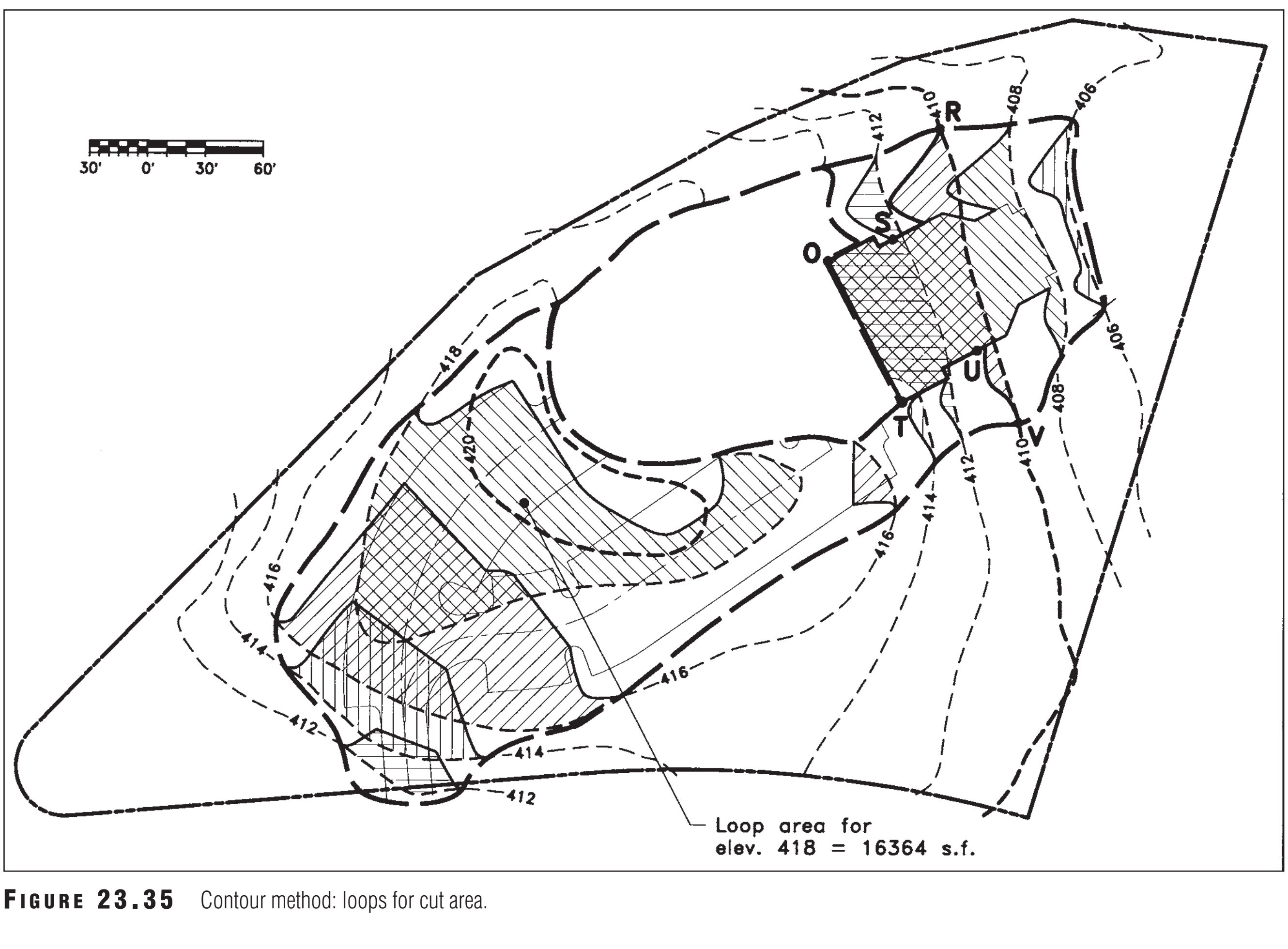


FIGURE 23.35 Contour method: loops for cut area.

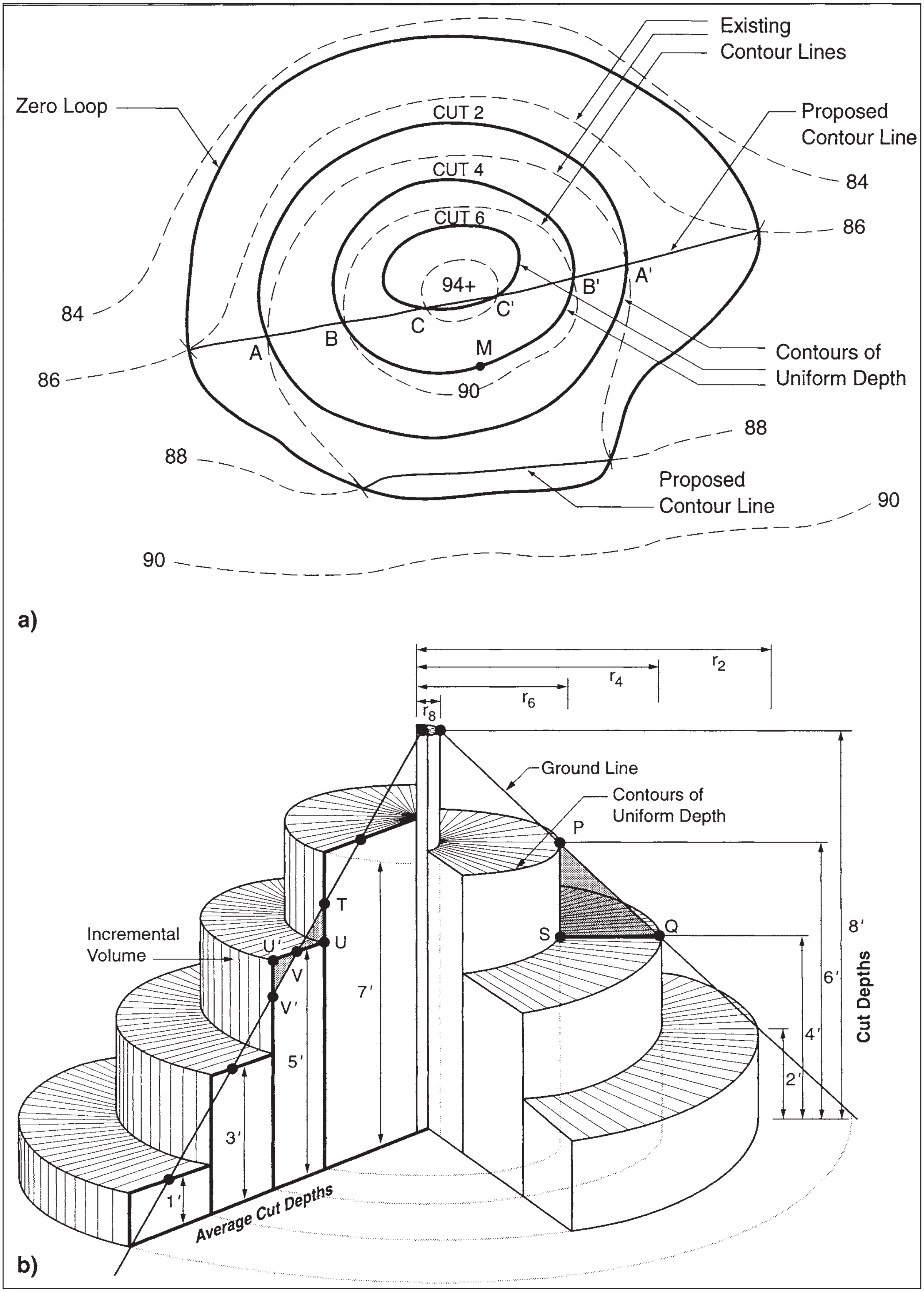


Figure 23.36 Contours of uniform depth for 8-foot-high mound.

The height of a ring represents a layer that is a constant depth above (for fill) or below (for cut) the original ground line. The constant distance is measured along the vertical direction from the ground surface. Although the equal planes method is predicated on layers of uniform depth of cut or fill parallel to the ground surface, as shown in the profile of the mound (Figure 23.37), the projection of these surfaces onto the plan view assumes these surfaces to be parallel to a horizontal plane, as shown in Figure 23.37.

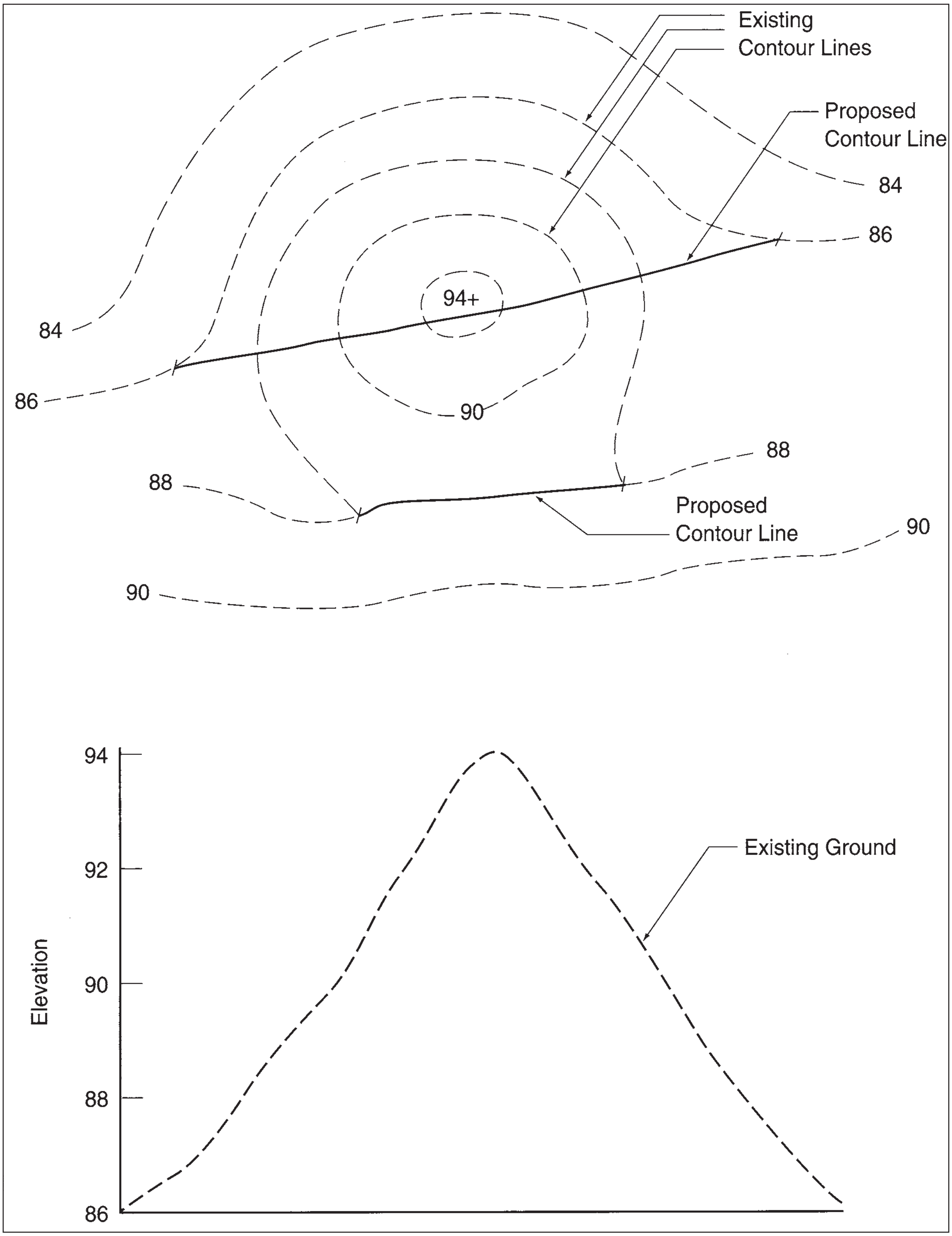


FIGURE 23.37 Plan and profile of mound showing layers of equal depths.

Figure 23.37 shows a profile view of the mound and the corresponding contours in plan view. The profile shows the underlying surfaces in increments of 2 feet. The first layer under the original ground represents a cut depth equal to 2 feet. In plan view this layer appears as a loop where the difference in elevation between the existing grade and proposed grade is 2 feet. Likewise, successive layers of 4, 6, 8, . . . -foot cuts are identified by loops where the difference in elevation between the existing and proposed grades are 4, 6, 8, . . . feet, respectively. Each loop is identified on the plan view illustration. A loop represents the inner edge on one shape and the outer edge of the subsequent inner shape. Hence, the difference in area between successive loops is the incremental area used to determine the volume of one of the rings. Summation of all incremental volumes is the estimated earthwork volume.

The basic procedure for using the equal planes method on a grading plan is as follows:

1. Delineate all loops representing equal cut or fill layers beginning with the zero loop. This loop identifies the plane where the grades tie out—essentially where the difference between proposed grade and existing grade elevations is zero. There could be more than one cut or fill area on a project. The zero loop isolates these individual cut and fill areas.

2. From each zero loop, work inward. Decide the next level for which a plane will be identified. It is easiest to keep the planes at the same increment as the contour interval. If the contour interval is 2 feet, the next plane would be at a depth/height of 2 feet. Inside the zero loop, locate the points where an existing contour intersects a proposed contour where the elevation difference between the two contours is 2 feet, as indicated by points A and A′ in Figure 23.36. A loop that connects these points and all points where the proposed elevation is 2 feet higher/lower than the existing elevation outlines a plane that is 2 feet higher/lower than the zero plane. A loop crosses contours only where the existing contour and proposed contour intersect—unless there is a retaining wall or other structure.

3. Decide the next plane. Again, if the contour interval is 2 feet, the next plane is at a depth/height of 4 feet. Draw a loop that connects all points 4 feet higher/lower than the existing elevation (points B and B′ in Figure 23.36). Continue this procedure inside all zero loops until all loops have been drawn for the site. The plan becomes more readable if two colors are used to draw the loops—one color for cut areas and another color for fill areas. Very light shading of alternate rings in the same color enhances the cut and fill areas. Large numbers written on the loops identify the depths/heights of cut/fill areas.

4. For each cut and fill area, a table keeps a record of the individual quantities and the accumulated earthwork, shown in Table 23.6. The area of each loop is determined and entered into Column 2. Column 3 is the difference between the current loop and the preceding loop. Column 4 is the average of the current depth and the preceding depth. Column 5 is the product of Column 3 and Column 4. Column 6 is the accumulated earthwork of Column 5.

EXAMPLE 3

Using the same grading plan as in the previous example, perform an ETO using the equal planes method. Figure 23.38 shows the grading plan with the zero lines, and the 2-foot, 4-foot, and 6-foot depths of cut loops as well as the 2-foot, 4-foot, and 6-foot depths of fill loops.

The area of each loop is determined and entered into Column 2 of Table 23.6. Column 3 of this table is the difference in area between two consecutive loops. Column 4 is the averaged depth of cut or fill, and Column 5 is the incremental volume = Column 3 × Column 4.

The main advantage to using the equal planes method is that the final plan view shows the cut and fill areas and how deep these areas are. Any adjustments to the site grades to adjust the ETO can be limited to specific areas.

Grid Method (Borrow Pit Method)

The grid method for computing earthwork quantities averages the cut or fill depths over a unit area. The product of the averaged depths with the unit area is the net incremental volume of cut or fill. A summation of all incremental fill volumes and cut volumes gives the total for the site.

Figure 23.39 shows a proposed ground surface and the existing ground surface for a unit area. (Note that the intersection of the two surfaces establishes the zero cut and fill line). The depth of cut or fill is written at each corner of the unit area. For this particular unit area, the average cut/fill is zero. That is, the volume of material in the cut area is equal to the volume of material in the fill area.

However as shown in Figure 23.40, the computations presume that the actual ground surface is a plane representing a linear ground surface. The areas that contribute to the error in the actual volume are shaded. The accuracy of the computed volume is a function of the size of the unit area and how close the representative planes for the existing and proposed ground approximate the true ground surface. As the undulations of the actual ground surface increase in number and deviate from the straight-line approximation, the precision of the computed volume decreases. To compensate for the irregular topography, the unit area can be reduced to increase precision. The penalty for this is the increase in number of grids and the computing time to perform the method. In some instances, decreasing the unit area may not be the solution either. On extremely flat sites, decreasing unit area size decreases the precision. For each unit area, an interpolation between contours is necessary to determine the elevations at each

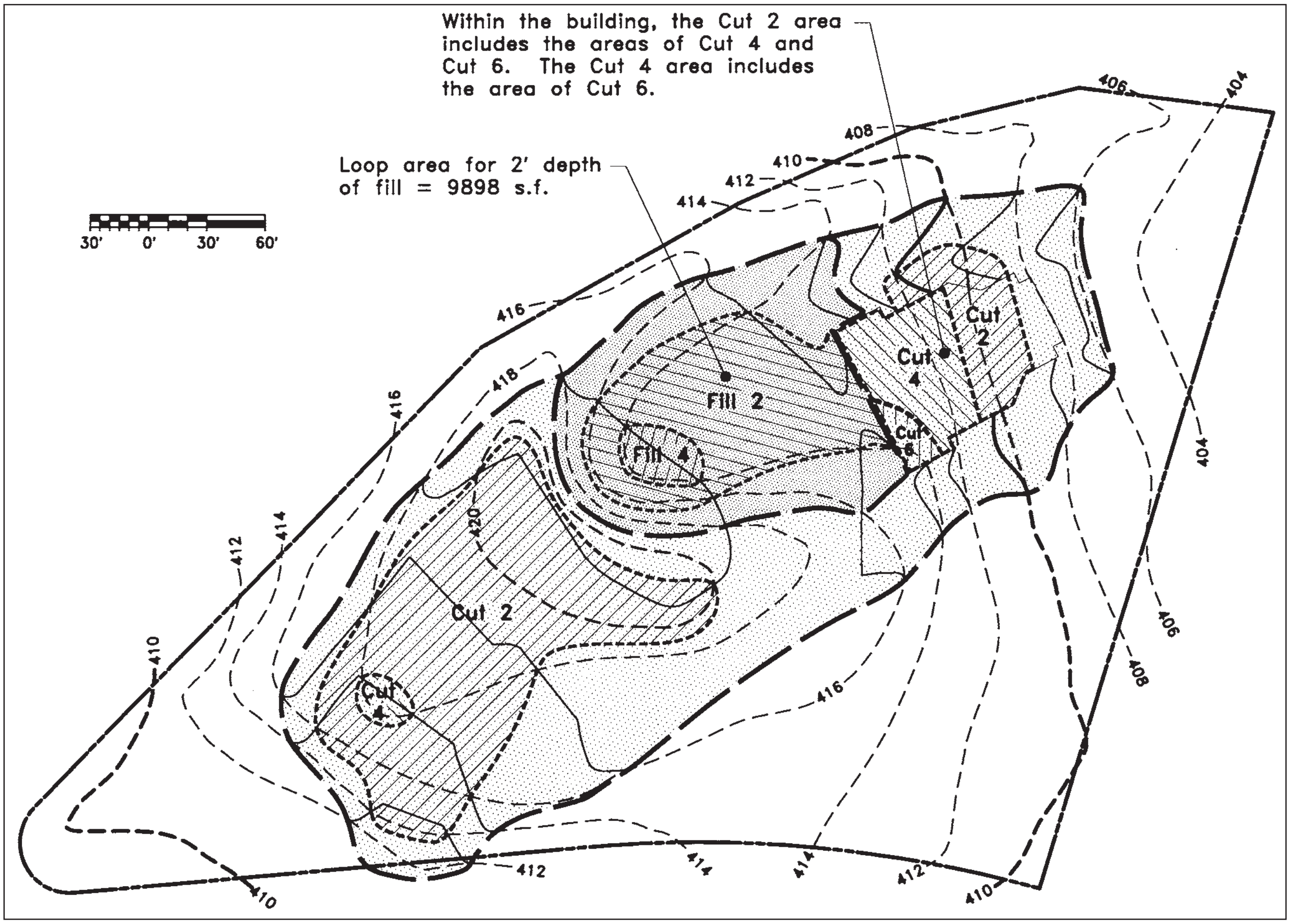


FIGURE 23.38 Cut and fill loops for equal planes method.

corner. Each interpolation calculation has an error associated with it. The propagation of this error contributes to the precision of the volume. In these extreme cases, the grid method may be abandoned in favor of an earthwork method that is more accommodating.

The mechanics of the method are as follows:

1. Obtain the grading plan of the site and create a grid of uniform-sized squares over the graded area. The procedure is facilitated if the grid is created on transparent material and overlain on the grading plan. For reasonably precise earthwork quantities, the grid squares should be 1-inch squares for plans with scales of 1 inch = 100 feet and larger.

2. The grid is overlain on the grading plan. At each corner of a square, a value is entered to identify the amount of cut or fill at that point. A positive value indicates fill, and a negative value indicates cut.

3. For each square, the cut/fill values are averaged and written in the center of the square; the incremental volume is the averaged cut/fill depths multiplied by the grid area. Only the corners of grid squares within the grading limits are used to obtain the average cut/fill values.

4. Any corner outside the grading limits is not included in the computational process. The incremental volume is the averaged cut/fill of these grid corners in the graded area multiplied by the fraction of the area of the grid within the grading limits.

5. Summing all averaged values within the grid squares is the net amount of excess/deficiency dirt. Summing all positive and negative numbers separately is the amount of cut and fill, respectively.

Figure 23.41 shows the grid method for the same grading plan with 1-inch grids. The cut or fill depths are written at the corners of each square (negative values indicate cut; positive values indicate fill). The value written in the center of the grid is the average cut or fill depth for that grid, that is, the sum of the values at the corners divided by the number of summed values. The volumes of cut or fill for each grid are determined by the product of the averaged cut or fill and the area of each grid. Some squares are not entirely within the grading area. The volume of cut or fill for these squares is

TABLE 23.6 ETO Computations for the Equal-Planes Method

(1) CUT DEPTH	(2) LOOP AREA (FT^2)	(3) DIFF. IN AREA (FT^2)	(4) AVG. DEPTH (FT)	(5) INCR. VOLUME (FT^3)
0	57,580			
		35,360	1	35,360
2	22,220			
		18,222	3	54,666
4	3998			
		3618	5	18,090
6	380			
		380	6.5	2470
7	0			
				TOTAL = 110,586 ft^3
				= 4,096 yd^3
FILL DEPTH				
0	17,468			
		7570	1	7570
2	9898			
		8930	3	26,790
4	968			
		968	4.2	4066
4.4	0			
				TOTAL = 38,426 ft^3
				= 1423 yd^3

found by multiplying the averaged cut or fill depth by the fraction of the area of the grid within the grading area. An "eyeball" estimate of the fractional area should suffice in most cases.

The grid on Figure 23.41 has four rows and eight columns. The incremental volume for each grid is given in Table 23.7.

Summing all of the fractions of the cut values and all of the fill values multiplied by the area of a grid gives the total volumes. The sum of the fractions of the cut and fill are 38.3 and 3.2, respectively. This corresponds to:

$$\frac{38.3 \text{ ft} \times (60 \text{ ft} \times 60 \text{ ft})}{27 \text{ ft}^3 \text{ per yd}^3} = 5100 \text{ yd}^3 \text{ of cut} \tag{23.15}$$

$$\frac{3.2 \text{ ft} \times (60 \text{ ft} \times 60 \text{ ft})}{27 \text{ ft}^3 \text{ per yd}^3} = 430 \text{ yd}^3 \text{ of fill}$$

The unusual low value for the fill volume (430 cubic yards) is due to the large grid size relative to the small fill area of the plan.

Comparing DTMs

When grading software is used to develop the grading plan, typically a proposed and an existing DTM exist. Rough earthwork quantities can be obtained by simply comparing the two DTMs. In general, the existing is considered the first (or bottom) surface and the proposed is the second (or top) surface. Thus, if the second surface is above the first, the volume that is contained in between is output as a fill volume, and if the second surface is below the first, the volume that is contained in between is output as a cut volume. The precise way

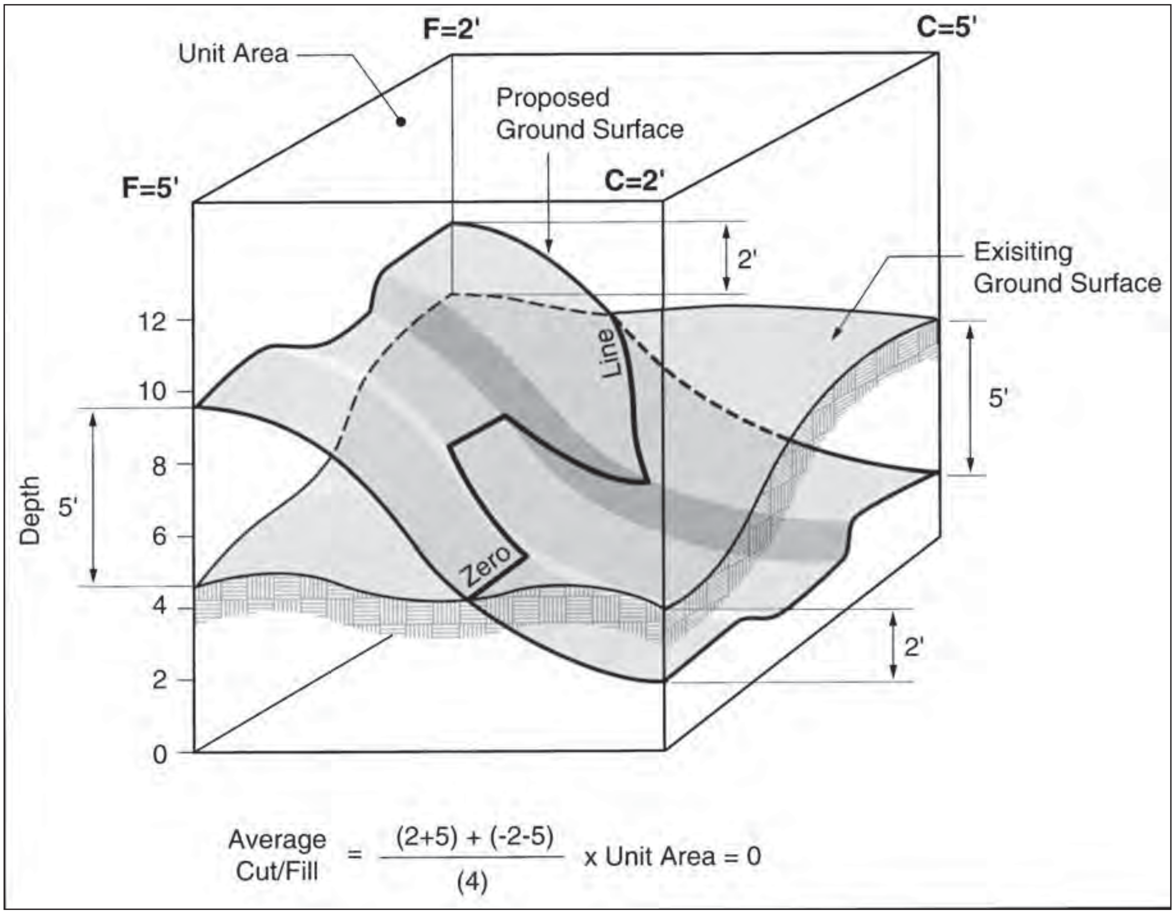


FIGURE 23.39 Ground surfaces for unit area of the grid method.

these volumes are computed may vary depending on the particular software that is being used, and each software package may offer more than one method for computing the volumes. One possible method is illustrated in Figure 23.42. In this example, the triangles of the proposed (upper) surface are projected onto the existing (lower) surface, forming a series of three-dimensional columns. The volumes of these columns are then calculated and summed by the computer.

ADJUSTMENTS TO EARTHWORK QUANTITIES

The ETO methods previously explained calculate the gross quantity of cut and fill; that is, the quantities are computed based on the existing topography and the proposed finished grades. Computing final earthwork quantities includes adjustments to the gross values of cut and fill to account for soil characteristics, topsoil, subbase allowance, foundations, and other items that affect the amount of displaced soil. Since earthwork is a major expense for a project, the adjustments are necessary, considering that they may affect the computed gross quantity by 10 to 30 percent. Frequently the client requests the adjustment quantities separate from the gross quantities. These adjustments are shown as separate volumes in a tabulated format. This can be helpful when determining causes for excess or deficient volumes. After all adjustments are made, the results are the net volumes of cut and fill.

Topsoil

Before any major grading operations begin, the site is stripped of the topsoil. The topsoil is stockpiled and used for planting and landscaping purposes when the project is nearly complete. In high-density residential projects and many commercial sites, very little area is available for landscaping. The resulting excess topsoil must be either hauled away or disposed on-site.

Topsoil depths generally range from 6 to 18 inches. Estimates for topsoil depths can be determined from the soils report and the soil boring logs of the site. If the soils report indicates a nearly uniform depth of topsoil, calculate the topsoil volume assuming a constant depth over the graded area. Some sites may have a large variation in topsoil depth over the site. The engineer decides whether to use a uniform depth or divide the site into areas of nearly uniform topsoil depth for calculations. The topsoil volume is the estimated depth multiplied by the graded area. In most cases, the earthwork quantity will not be adversely affected if the topsoil depth is assumed uniform over the entire graded area. Another, more time-consuming method is to actually draw the topsoil depth

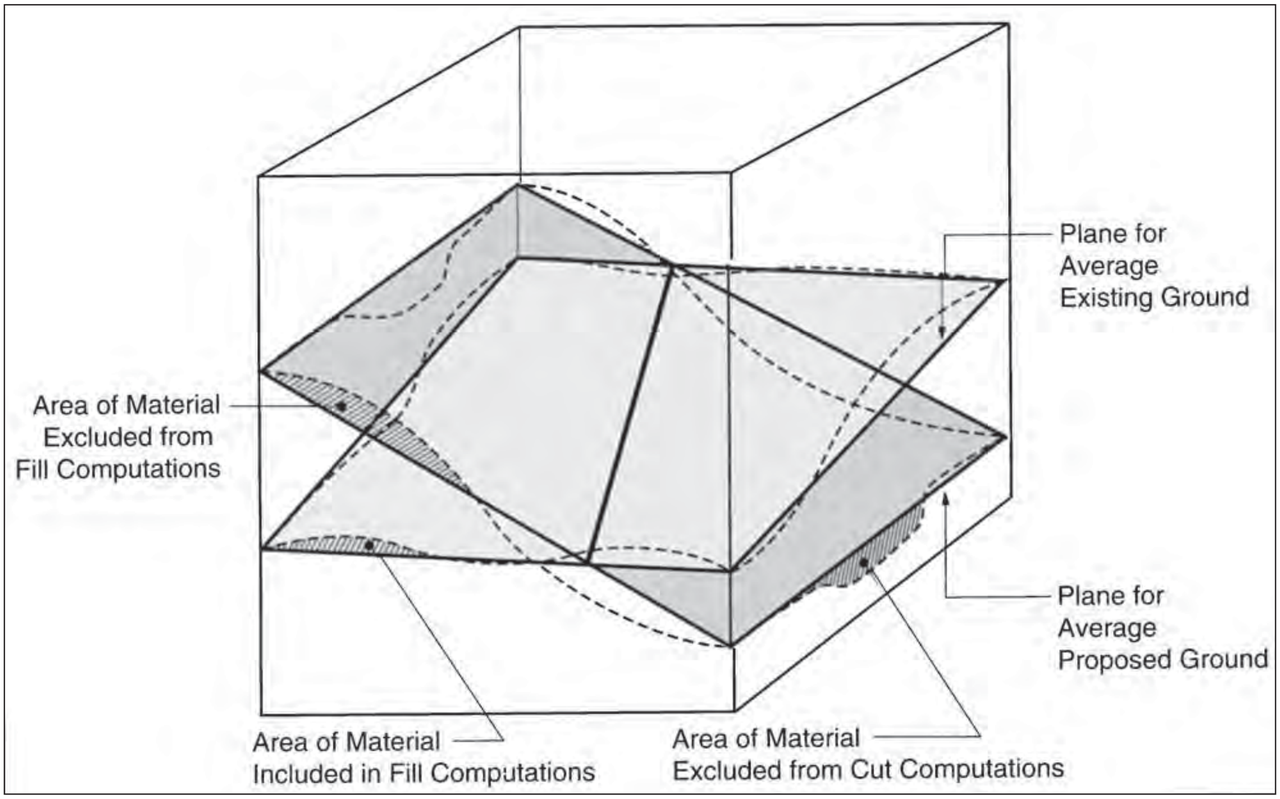


FIGURE 23.40 Average ground surface by linear approximation.

on the cross-section drawings and calculate the topsoil quantity using the average-end-area method. This procedure is followed when cross sections of the site are available and the topsoil depth is highly variable.

The gross volume of topsoil to be stockpiled is equal to the topsoil stripped from both the cut and the fill areas. The stripped volume of topsoil from the cut areas is subtracted from the gross cut volume.

Conversely, the volume of topsoil stripped in the fill areas is added to the gross fill volume. The sum of these two values is the volume of stockpiled topsoil. Topsoil reused in vegetated areas is replacement topsoil. The vegetated areas are determined for both the cut and the fill areas of the site. Calculated replacement topsoil volumes in the vegetated areas of the cut areas are added to the gross cut quantity, and the replacement topsoil volumes in fill areas are subtracted from the gross fill quantity. The stockpiled topsoil volume less the replacement topsoil volume is the net topsoil remaining.

Referring back to the grading plan used in the ETO examples, the area of topsoil to be considered is that contained within the zero loops. The area of the zero loop for the cut area is 58,268 square feet. An assumed uniform topsoil depth of 6 inches equates to approximately 1100 cubic yards of topsoil. Likewise, within the fill area loop of 18,711 square feet, the approximate topsoil volume is 350 cubic yards. The vegetated area in the cut area is 26,200 square feet, and in the fill area it is 8000 square feet. Using a replacement topsoil depth of 14± inches results in using all of the stockpiled topsoil tabulated in Table 23.8.

When using computer modeling to determine earthwork quantities, the existing grade DTM is modified to represent the site after the required topsoil has been stripped. The modified DTM is the surface that will then be compared to the proposed surface. This eliminates the need to make manual adjustments to the cut and fill quantities.

Subbase and Concrete Pads

Roads, concrete slabs, and building pads consist of different layers of gravel, coarse aggregate, concrete, and wearing surface. The total thickness of these layers depends on the bearing capacity of the soil and the type of structure, and ranges from 8 inches to 2 feet in typical situations. In extreme cases, the thickness might be double these depths. Concrete pads and the subbase for resident houses has a thickness of 8 to 12 inches. Concrete pads and subbase for parking structures and high-rise commercial buildings typically are 18 to 24 inches thick. The pavement structure for roads may be 12 to 18 inches thick.

To account for subbase and concrete thickness, the earthwork quantity is based on the subgrade 10 elevation rather than the finished grade elevation. Therefore, in cut areas the base volume of the cut must be increased by the total volume of the subbase, pavement, and concrete. In fill areas, the

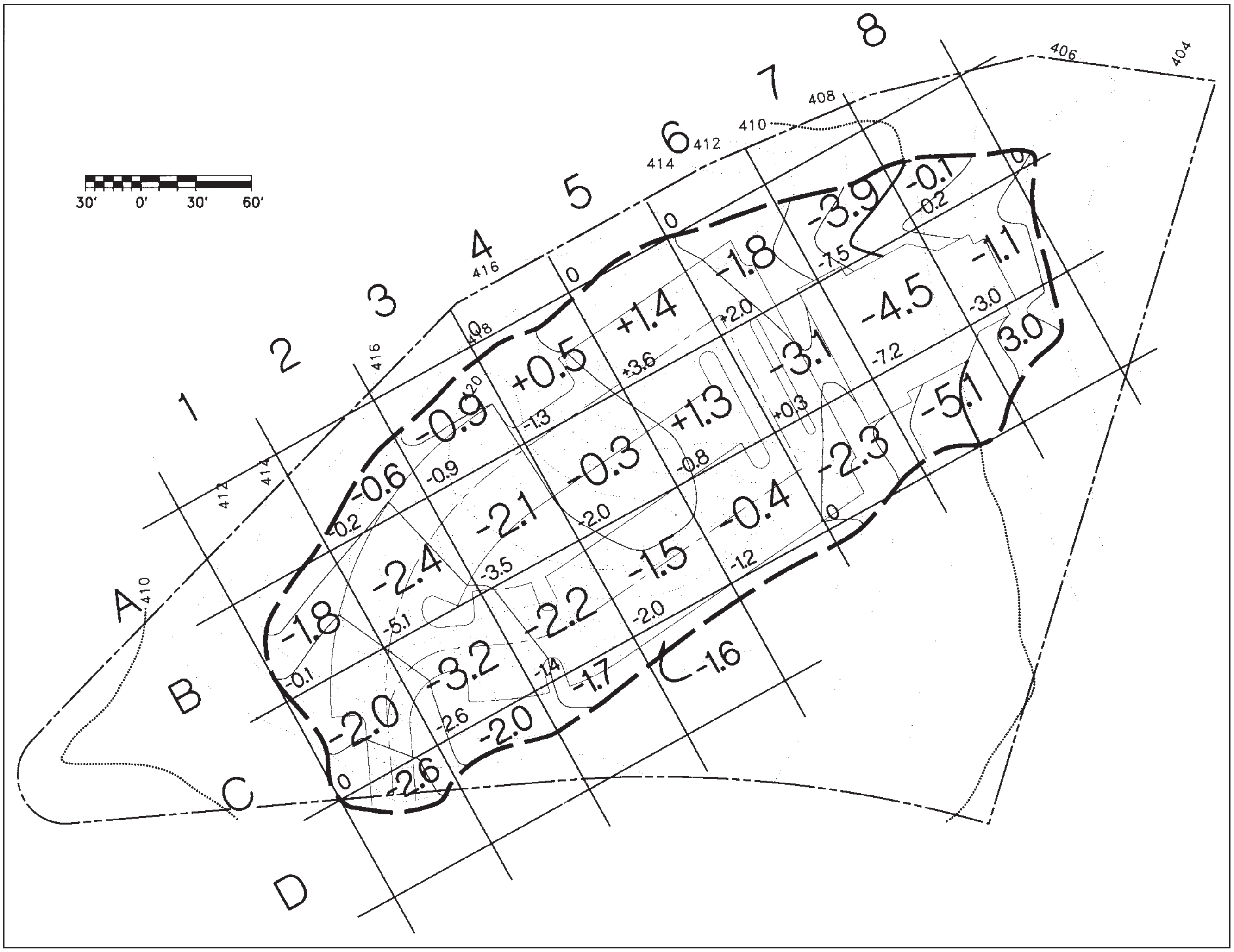


FIGURE 23.41 Grid method for ETO.

pavement and subbase volumes are subtracted from the base value of the fill volume.

Following through on the ETO example problem, assume the combined pavement and subbase thickness is 10 inches. The area of pavement in the cut area and the fill area is determined (by planimeter) to be 25,000 square feet and 10,000 square feet, respectively. The building pad has combined concrete and coarse aggregate layer thickness of 12 inches and a footprint area of 7000 square feet. The adjusted earthwork volumes for these items are shown in Table 23.9.

When using computer modeling to determine earthwork quantities, it makes sense to create a DTM that represents the surface that will result from mass grading of the site. For example, the elevations defining the roadway would be set at the bottom of the roadway box and not at finished grade. This would also hold true for concrete pads and building foundations. In the case of mass grading for residential subdivisions—where the lot is initially constructed lower than finished grade—the mass grade elevations would be incorporated into the surface.

This DTM would, for the purposes of earthwork calculations, be considered the proposed surface. This DTM would then be compared to the modified for topsoil stripping surface (as previously described) to determine the earthwork quantities. This eliminates the need to make manual adjustments to the cut and fill quantities.

Utilities

Accounting for soil volume for relatively narrow, shallow trenches is not typically done. As an example, the volume of a trench 6 feet deep and 3 feet wide is equal to 0.67 cubic yards per linear foot. The volume of a 15-inch conduit with 6 inches of bedding material is 0.10 cubic yards per linear foot. If a 15 percent shrinkage factor is assumed, then the additional amount of soil required for backfill is compensated for by the volume of conduit and bedding.

However, when the size of the trench becomes larger or deeper than the shallow example described here, the amount of trench backfill should be accounted for. The backfill volume is the volume of the trench less the volume of conduit and bedding plus allowance for shrinkage.

TABLE 23.7 Incremental Cuts and Fills for ETO Grid Method Example

Grid (Row × Column)	Avg. Cut or Fill Depth	Fraction of Grid	Fraction of Cut or Fill	Grid (Row × Column)	Avg. Cut or Fill Depth	Fraction of Grid	Fraction of Cut or Fill
(A,1)	0	0	0	(A,5)	+1.4	1	+1.4
(B,1)	–1.8	0.8	–1.4	(B,5)	+1.3	1	+1.3
(C,1)	–2.0	1	–2.0	(C,5)	–0.4	1	–0.4
(D,1)	–2.6	0.5	–1.3	(A,6)	–1.8	0.8	–1.4
(A,2)	–0.6	0.4	–0.2	(B,6)	–3.1	1	–3.1
(B,2)	–2.4	1	–2.4	(C,6)	–2.3	0.9	–2.1
(C,2)	–3.2	1	–3.2	(A,7)	–3.9	0.6	–2.3
(D,2)	–2.0	0.4	–0.8	(B,7)	–4.5	1	–4.5
(A,3)	–0.9	0.7	–0.6	(C,7)	–5.1	0.7	–3.6
(B,3)	–2.1	1	–2.1	(A,8)	–0.1	0.3	–0.3
(C,3)	–2.2	1	–2.2	(B,8)	–1.1	0.6	–0.7
(D,3)	–1.7	0.4	–0.7	(C,8)	–3.0	0.3	–0.9
(A,4)	+0.5	0.9	+0.5				
(B,4)	–0.3	1	–0.3				Σ Cut = 38.3 ft
(C,4)	–1.5	1	–1.5				Σ Fill = 3.2 ft
(D,4)	–1.6	0.2	–0.3				

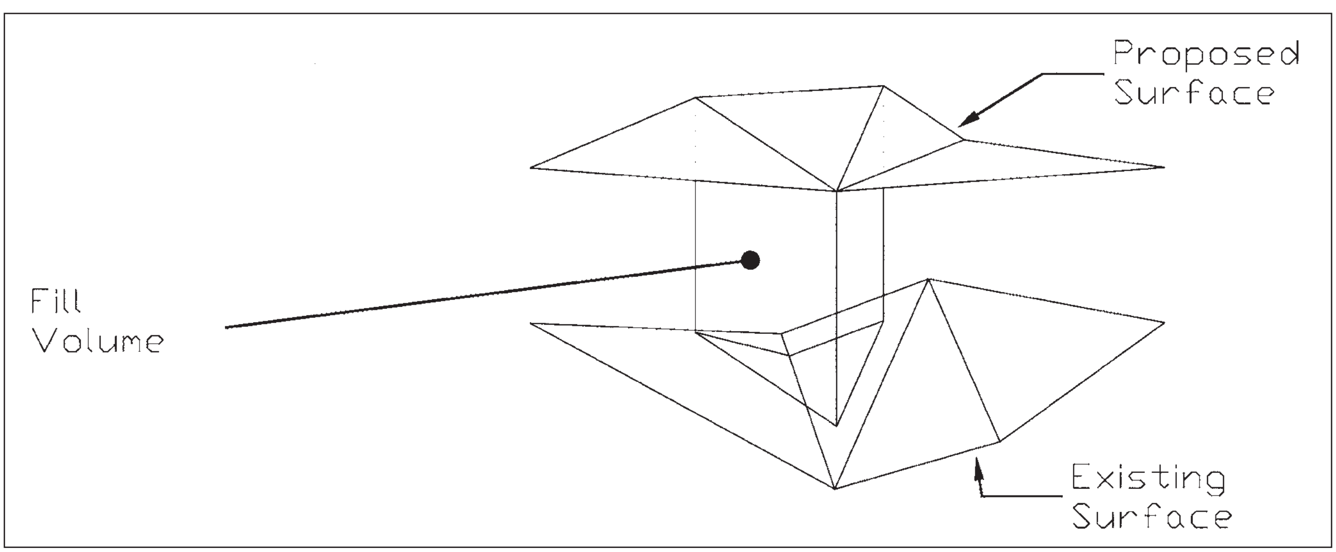


FIGURE 23.42 Comparing DTMs.

TABLE 23.8 ETO Values Adjusted for Topsoil Depth

ADJUSTMENT	CUT VOLUME (YD^3)	FILL VOLUME (YD^3)
Gross	4096	1423
Strip topsoil (6 inches)	–1100	+350
Replacement topsoil (14 inches)	+1130	–345
Adjusted volume =	4126	1428

Undercut

Another adjustment to the ETO must account for the inadequate bearing capacity of the underlying soil or other bad soil conditions (e.g., high shrink/swell characteristics) or underlying rock layers. Although a thorough subsurface investigation performed during early planning stages usually alerts the design team about these undesirable conditions, small pockets of poor soil conditions and rock layers may not become evident until excavation exposes them during construction. Nonetheless, the removal (undercut) and replacement of this unsuitable material must be accounted for in the earthwork quantities. If such conditions cover wide areas and extend to great depths, the removal and replacement with acceptable material becomes costly.

The undercut quantity is added to the cut volume as well as the fill volume.

TABLE 33.9 ETO Values Adjusted for Subbase, Pavement, and Concrete Thickness

ADJUSTMENT	CUT VOLUME (YD^3)	FILL VOLUME (YD^3)
Gross	4096	1423
Strip topsoil (6 inches) replacement	–1100	+350
Topsoil (14 inches)	+1130	–345
Building pad (12 inches)	+260	–0
Pavement (10 inches)	+770	–310
Adjusted volume =	5156	1118

When using computer modeling to determine earthwork quantities, making adjustments to the earthwork quantities to account for undercut can sometimes be facilitated by using DTMs.

Take, for example, a site that has bedrock so close to the surface that rock needs to be removed to achieve finished grade. Further, assume that there is also rock exposed at existing grade. In this scenario, the amount of cut would need to be adjusted by the amount of rock removal and the topsoil stripping quantity would need to be adjusted per the surface rock. Figure 23.43 illustrates this concept.

If you consider the lines in Figure 23.43 to be surfaces, it is easy to see that Area A represents the amount of rock that would need to be removed. By comparing the proposed (mass) grade DTM to a DTM representing the surface of rock, the volume of rock removal would be determined (equal to the cut quantity generated by that comparison). The site earthwork cut quantity would be adjusted by subtracting the rock removal quantity.

If there are areas on the site where bedrock is so close to the surface that there is a thinner layer of topsoil or no topsoil at all, the topsoil stripping quantity would need to be adjusted per the amount of rock encroachment. In Figure 23.43, Area B represents the volume of rock encroachment and can be determined by comparing the rock surface DTM to the DTM that represents the existing surface after the topsoil has been stripped. The amount of rock encroachment would be the fill volume for this comparison and would be subtracted from the topsoil stripping quantity.

Shrinkage

Soil volume increases when it is displaced from its natural state due to the increase in the amount of voids. Relative to soil in a natural state, soil used as compacted fill has a higher in-place density in most cases. If the same dirt excavated from a 1-cubic-foot hole is placed back into the hole without any compaction efforts, there will be excess dirt. Later, a depression appears in the hole area as the result of natural settlement. If the dirt is placed back into the hole at a density higher than its natural state, there will not be enough dirt to fill the hole. With the added compaction, the amount of voids is less than the amount of voids of the naturally consolidated soil, hence, the deficiency in excavated soil volume. This apparent decrease in volume of excavated soil is referred to as *shrinkage*. The ratio of the remaining volume of the excavated hole after the original dirt has been replaced (with compaction) to the total volume of the hole is the shrinkage factor. The amount of shrinkage can be measured relative to the volume of excavated material or relative to the volume of required fill.

To illustrate this last statement, consider a soil with a density of 90 pounds per cubic foot, with 21.2 percent water content in its natural state. Laboratory test results show that this same soil has a maximum density of 110 pounds per cubic foot at optimum moisture content (OMC).

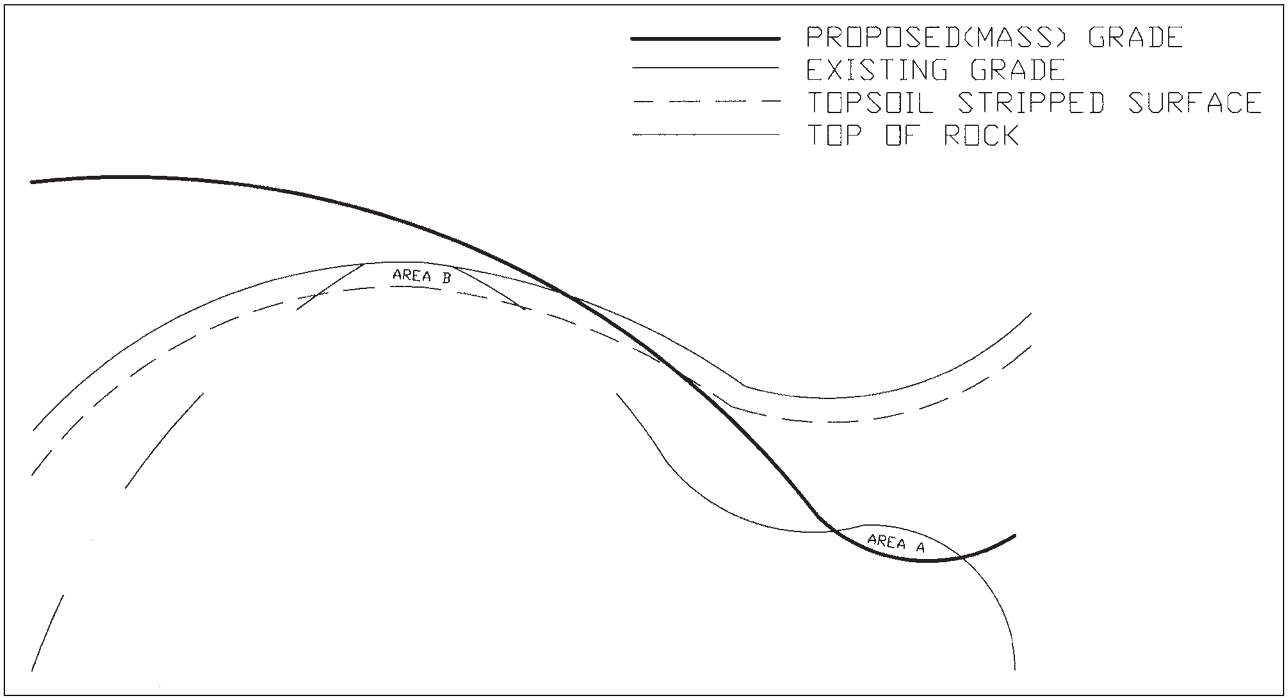


FIGURE 23.43 Cross section of site with rock.

(a) If a site requires 10,000 cubic yards of fill at maximum density, how much borrow material should be excavated?

To compute soil volumes in going from borrow to fill or fill to borrow, recognize that density is inversely proportional to volume. The relative ratios of the borrow and fill densities and volumes can be expressed as:

$$\frac{D_b}{D_f} = \frac{V_f}{V_b} \tag{23.16}$$

where the *b* and *f* subscripts refer to borrow or fill. Therefore, the required borrow volume is:

$$\frac{90 \text{ lb/ft}^3}{110 \text{ lb/ft}^3} = \frac{10{,}000 \text{ yd}^3}{V_b} \tag{23.17}$$

or $V_b \approx 12{,}200 \text{ yd}^3$

(b) How much volume will 10,000 cubic yards of borrow material occupy if placed at maximum density?

$$\frac{90 \text{ lb/ft}^3}{110 \text{ lb/ft}^3} = \frac{V_f}{10{,}000 \text{ yd}^3} \tag{23.18}$$

or $V_f \approx 8{,}200 \text{ yd}^3$

What is the relative change in volume in parts a and b?

Part a:

$$\frac{12{,}200 \text{ yd}^3 - 10{,}000 \text{ yd}^3}{10{,}000 \text{ yd}^3} = 22\%$$

Part b:

$$\frac{12{,}200 \text{ yd}^3 - 10{,}000 \text{ yd}^3}{12{,}200 \text{ yd}^3} = 18\% \tag{23.19}$$

Part c shows that relative to the required fill volume, 22 percent more borrow material is required, and relative to a given borrow volume the material reduces only 18 percent in volume when placed at maximum density. Notice that the borrow volume reduces by the same amount in both cases, that is, (12,200 – 10000)/12200 = 18 percent and (10,000 – 8200)/10000 = 18 percent. The point here is to recognize that careful attention is warranted when specifying volumes for fill and excavation projects. Payment for fill dirt is typically based on the amount required to fill the hole (as shown in part a) and not the volume of the hole itself. However, in most cases the cost of doing the work is based on the amount of soil excavated. Since the density of excavated soil is less than its natural-state density, allowances must be made for computing haul quantities.

Typical shrinkage factors might range from 10 to 30 percent depending on the type of soil, the amount of compaction, and the amount of losses expected in hauling. In the previous example, the natural soil density is known. In most cases the natural soil density is unknown and the engineer must use judgment in estimating the shrinkage to make an adjustment. This adjustment is typically made by increasing the amount of fill that is reusable. This accounts for the increased amount of soil required as a result of compaction.

Referring back to the ETO example, the assumed shrinkage factor is 20 percent. The measured fill volume is 1095 cubic yards. This requires 1.2(1095) = 1314 cubic yards. Assuming the cut volume is adequate for use as compacted fill, the resulting excess is 4560 − 1314 = 3246 cubic yards. This can be hauled away to be used as compacted fill elsewhere. The remaining 3246 cubic yards of excavated material converts to 0.8(3246) = 2600 cubic yards of fill material.

Table 23.10 shows the final tabulation to account for earthwork adjustments.

EARTHWORK SUMMARY

As noted at the beginning of the discussion on earthwork, it is very important to design a balanced site. This is because the movement of soil can be very expensive, often the single most costly construction item. Earthwork computations and/or digital modeling can be time consuming; however, the time spent is more than justified by the amount of money that can be saved by reducing the amount of material that must be wasted or hauled in a surplus cut situation or minimizing the amount of material that must be purchased and brought to the site in an excess fill situation. The designer should prepare ETOs throughout the design process in order to accurately quantify the required earthwork as well as develop a design that will optimize earthwork efforts.

TABLE 23.10 Tabulated ETO Values

Adjustment	Cut Volume (yd^3)	Fill Volume (yd^3)
Gross	4096	1423
Strip topsoil (6 inches) replacement	1100	+350
Topsoil (14 inches)	+1130	–345
Building pad (12 inches)	+260	–0
Pavement (10 inches)	+770	–310
Undercut	+0	+0
Large conduits and structures	+0	—
Subtotal =	5156	1118
Shrinkage (20%)		+224
Net fill volume =		1342
Net cut volume =	3814	

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ADDITIONAL INFORMATION

For additional information on computer-aided design software, smart drawings, land development software, and digital terrain models, go to the following sites on the World Wide Web:

www.autodesk.com

www.bentley.com

CHAPTER 24

WASTEWATER COLLECTION

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OVERVIEW

Proper management of wastewater is one of the most important factors for ensuring the general health of a community and its surface water quality. Much has been written about the early sewer systems, such as the underground drains installed in ancient Rome, but these early sewer systems were generally storm drains. In most urban areas, it was unlawful to discharge sanitary sewage into these drains prior to the mid-1800s. Thus, the history of sanitary sewers only covers the period from the mid-1880s to the present.

Major construction of sewer systems in many communities occurred during the 1930s period of economic depression as a part of the federal government's Works Progress Administration (WPA) program. Many smaller communities obtained their first central sewer system and sewage treatment facilities as a part of this program. This was the first significant period of sanitary sewer construction in this country. This period was also noted for the significant increase in the popularity of indoor plumbing.

World War II was a period of both urban and industrial growth throughout the United States. At the end of the war, many segments of surface streams were excessively polluted. Two of the reasons were the substantial increase in the discharge of untreated industrial wastes and the untreated overflow from combined sewers. Many older urban areas installed storm drains prior to the time of widespread adoption of indoor plumbing. When indoor plumbing became fashionable, the building sewers were connected into the existing storm drains. These combined sewer systems generally drained directly to the nearest watercourse without treatment of the flow. Also, the wastewater collected in many sanitary sewer systems received little or no treatment prior to its discharge into surface waters at that time.

The U.S. Public Health Service was the federal agency responsible for water quality–related matters prior to the establishment of the Federal Water Quality Administration in 1968. This agency later became the Environmental Protection Agency. It should also be noted that at this time federal agencies had little control over intrastate matters related to the environment. The U.S. Public Health Service, private organizations and universities in the United States, Great Britain, and Europe were conducting research and studies related to stream water quality and waterborne diseases as early as the last half of the nineteenth century. One of the most significant contributions to water quality knowledge in the first half of this century was the work of two U.S. Public Health Service officers, published in 1925, on the analysis of the oxygen balance in streams. This classical work of Streeter and Phelps remains the basis for modeling stream quality today.

It was only after World War II that the individual states began to establish agencies and enforce regulations controlling surface water pollution. The Water Quality Act of 1972 (P.L. 92-500) was the first legislation giving the federal government authority to set requirements and enforce standards on a national basis. This legislation, together with the federal funding for water quality programs and facilities, has changed the quality of sewer system design and construction.

A primary limitation to the effectiveness of any water pollution control program prior to the 1970s was the poor quality of sewage collection systems. Most community sewer systems were in a state of disrepair because of the lack of suitable materials for use in construction, poor construction practices, and poor maintenance. From 1950 to 1970, while significant progress was made in the construction of sewage treatment facilities, most sewer systems, pumping stations, and treatment facilities were still subject to flooding, overflow, and bypassing of flow, particularly during wet periods.

Segments of some sewer systems, primarily in older, larger communities, are still combined sewers. Thus, during wet periods, overflow and bypassing may occur with these systems. Federal and state programs are attempting to correct these conditions, as funds become available.

P.L. 92-500 established regulations and timetables for eliminating pollution on a uniform national basis. To accomplish these new goals it became necessary to design proper reliability into new sewer systems and to rehabilitate existing sewers. This meant using suitable construction materials and methods. The engineers of today have suitable materials and technology to design and construct sewer systems that will eliminate problems with both infiltration and exfiltration. New sewers, when designed and constructed to today's standards, should provide reliable service for many years.

The design engineer now has several choices of suitable pipe material for use in sewer construction that will provide long service and near 100 percent exclusion of both infiltration and exfiltration. Proven design procedures are available to the engineer for sizing and routing of sewers to ensure that the completed project will properly serve the contributing area. The design engineer must be thoroughly familiar with federal, state, and local laws and regulations before proceeding with a design.

This chapter presents material that, when properly applied, will result in a reliable and effective sewer system design.

Glossary of Terms

This glossary includes common terms used in regard to sewer systems. Many other terms are defined in the text as they are used.

Sewer: A conduit for conveying wastewater. Sewers may be designated as sanitary, industrial, or storm depending on the type of flow being conveyed. Sanitary sewers convey sanitary sewage that originates in a community. All the wastewater flow from a community—the flow from residential areas, commercial areas, and normal community industry such as laundries, restaurants, and service stations—is designated as domestic wastewater. Sanitary sewers are generally closed circular conduits. They are designed such that the hydraulic gradient is below the inside crown of the conduit (see section entitled "Hydraulics of Sewers").

Sewage (Wastewater): The liquid conveyed by a sewer. *Wastewater* is now the more common term. Sewage may be designated as domestic, industrial, or storm to indicate the source. Domestic sewage is also called *sanitary sewage* or *wastewater.*

House (building) spur or lateral: The conduit between the building foundation and the sewer owned and maintained by the local utility. The uppermost segments of a sewer system may also be designated as a lateral (where no other public sewer discharges into the segment). It is common practice for the local utilities to maintain the building lateral segment between the public sewer and the property line.

Submain, Main, and Trunk sewers: These terms are used subjectively in defining the type of sewer. Trunk sewers are generally the main conduits receiving the flow from a large area and would include the flow from several submain and main sewers.

Interceptor sewers: A conduit that intercepts other sewers, such as the sewer routed along a stream and intercepting sewers in the collecting system.

Outfall sewer: The conduit between the treatment facility and the receiving body of water. Also, the trunk sewer between the collection sewers and the treatment facility is often designated as an outfall sewer.

Combined sewers: A combined sewer refers to the older systems where the initial drainage was storm drainage. Before the mid-1900s it was not uncommon for sanitary sewers to be connected to existing storm sewers. Thus, the sewers conveyed sanitary and storm wastewater and were designated as combined sewers. These combined sewers generally discharged directly to a nearby body of water without treatment. Since all wastewater is now treated prior to discharge, combined sewers are no longer constructed.

Manhole: An opening to a sewer for inspection and maintenance. Manholes are generally placed at all sewer intersections, at all changes in alignment and grade of a sewer system, and at least every 400 feet. The manhole structure usually consists of a barrel section with a vertical 4-foot diameter, a top cone section reducing the circular opening to 2 feet, and a cast-iron frame and cover with a 2-foot opening.

Infiltration and Inflow: Infiltration is ground water that enters the sewer system. An infiltration problem results from broken and cracked sewers, from poor pipe material and poor joints, and from poorly constructed manholes. Additionally, concrete and clay pipes are semipervious and thus susceptible to *barrel weeping*, a principal source of infiltration in sewer systems employing these materials. Local design standards generally limit infiltration to less than 100 gallons per day per inch-mile (length of sewer line in miles multiplied by the diameter in inches). However, the engineer now has several excellent sewer pipe materials available that should provide a completely waterproof line when properly installed.

Inflow is surface water that enters the sewer system. The principal sources of inflow include inundation of manholes and unauthorized connections. Unauthorized connections can include the building of downspouts, area drains, and other connections of storm sewer to the sewer system. Ideally, all storm or surface water should be excluded from sanitary sewers.

Exfiltration: The seepage of sewage from the sewer system into the surrounding soil. Exfiltration may result from the same physical conditions as listed previously for infiltration. Infiltration may occur when the water table is above the sewer elevation, and exfiltration may occur when the water table is below it.

Sewerage: Sewage works, including the facilities for collection and conveyance of sewage.

Pump Station and Forcemain: A mechanical means of conveying collected sewage, usually over an area that cannot utilize gravity flow. A pump station normally consists of a structure to collect and hold the sewage, pumps to add energy to sewage and lift it over the land obstruction, controls to work the pumps, and a forcemain or pressure line to use for the conveyance of the sewage to a gravity system or wastewater treatment works.

Parties Involved in the Planning and Design of Sewer Systems

The design of any sewer system always involves several parties. Input from all impacted parties should be organized early in the design. The design engineer must be familiar with the local, state, and federal laws and regulations as they apply to the proposed design. The local government and often a state agency must approve the design and issue a permit for construction. Also, it is important to determine whether the downstream segments of the sewer system and the treatment facilities that receive the flow have adequate capacity. If not, a treatment plant and disposal of the treated effluent must be a part of the planning phase. The general responsibilities of the principal parties are discussed next.

Sewer system planning and design are normally a part of the overall project plans. The overall project plans should show all infrastructure, and the construction contract should provide for coordination of all utilities to be constructed.

Owner: The owner is the party that initiates the project. The owner may be a local government or utility or it may be a landowner or developer.

Legal Counsel: Legal counsel is generally needed by the private owner early in the planning stage of a project. Legal counsel provides direction to the project with respect to property rights, zoning requirements, and so on. In most urban areas, attorneys who specialize in legal requirements and procedures for land development can be found.

Engineer: The engineering firm offering services in sewer design is generally staffed to provide complete professional services, including both surveying and engineering. Thus, the term *engineer* as used herein refers to an organization that offers consulting services capable of handling the project from the beginning through the completion of construction and acceptance by the owner.

Regulatory Agencies: The engineer must be knowledgeable in the laws and regulations related to the project. It is common for sewerage projects to be under both state and local regulations. One or both levels of government may review the plans and specifications and issue a permit for construction. Generally, these agencies inspect the completed project before it is placed in operation. Most regulatory agencies have minimum design standards that represent good design practice and also ensure uniformity throughout the sewer system, which is important to the maintenance staff. It is critical that the engineer be well informed on all local design standards and procedures.

Contractor: The contractor is responsible for constructing the project in accordance with the plans and specifications.

DESIGN OF SEWER SYSTEMS

Characteristics of Sewage

Sewage is a water transport means of conveying wastes from the source. Domestic sewage conveys wastes from dwellings and the normal business, commercial, and industrial activities associated with any community, such as restaurants, laundries, and service stations. Sewage also contains the dissolved inert chemicals from the water supply as well as dissolved and suspended organic matter from the sources. The primary source of the material in sewage is the bathroom, kitchen, and laundry. Sewage also contains very high concentrations of bacteria and viruses. Sewage should always be considered as being a source of enteric pathogens.

Since sewage behaves hydraulically as water, the design engineer is only concerned with the composition of sewage when it contains substances that may be damaging to the sewer system or maintenance personnel. Principal substances of concern include those that are corrosive, present potential fire or explosive hazards, emit toxic fumes, or interfere with downstream wastewater treatment. Normal domestic sewage does not contain hazardous constituents other than pathogens. However, poor design or construction can create hazards. The accumulation of solids can result in the creation of odors as well as corrosive and toxic gases from the decomposition of the solids.

Domestic sewage is more than 99.9 percent water and generally between 0.05 to 0.075 percent dissolved and suspended solids. The level of organic matter in sewage is indicated by varying degrees of strength or weakness. A weak sewage generally results from high infiltration to the sewer system. A strong sewage indicates the presence of industrial wastes. There is little difference in sewage strength that is related to living standards.

The two most important parameters for defining the strength of sewage are the biochemical oxygen demand (BOD) and suspended solids concentration. BOD is a measure of the amount of organic matter present, expressed in terms of the oxygen required to biologically oxidize the material to a stable form. A 5-day period is generally used for the test. Thus, the five-day BOD is an expression for the strength of sewage. The use of a broad test of this type is necessary because sewage is a mixture of many organic compounds, making it nearly impossible to conduct a complete chemical analysis. Furthermore, many of the compounds present are partly refractory to biological oxidation, making a chemical analysis meaningless. The BOD test measures the strength in a manner that most nearly represents treatment accomplishment and potential impact of the flow on the receiving body of water.

Suspended solids concentration is also an important characteristic of domestic sewage. The sewer system must be designed to transport the solids. Suspended solids also represent a load to the treatment plant. Solids not removed in the treatment process may accumulate on the bottom of the receiving stream and create a pollution problem. The suspended solids in domestic sewage are generally more than 80 percent organic matter. These solids originate from fecal material, laundry, and kitchen wastes. Sewage will contain some organic material from laundry and kitchen wastes. Inorganic matter also originates from washing vegetables and from laundry wastes. Inorganic suspended material is known as *grit* or *fixed solids.*

Table 24.1 presents information on the range of strength-related parameters for domestic sewage that may be of interest to the sewer design engineer. Textbooks and other sources present more detailed analyses of sewage that would be of interest in the design of treatment works.

Quantity of Sewage

All wastewater management facilities should be designed to serve the needs of the contributing area for some time into the future. The design engineer for a wastewater treatment facility may use several methods for determining future design populations. These methods will always include population projections for the design period. In sewer design, the engineer needs to know the area to be sewered and the developed density. The developed density will depend on the planned or zoned activity. The area to be served can be established from available maps or from field surveys. Most areas subject to being sewered should be included in a comprehensive plan or have been zoned for a specific land use. The use of this information permits the design engineer to establish sewage flow for an area at complete development. This information can then be used to establish sewage flow for each segment of the sewer to be designed. Sewers are normally designed to sewer the tributary land area at complete development. Specific conditions, such as political boundaries or land use planning, may also dictate the design area. It is important to design a sewer with sufficient capacity to serve the area for at least 25 years. Regulations of the local utility may control the area to be included in the design and the design requirements.

TABLE 24.1 Strength of Sewage in mg/L

	CONSTITUENT		
	WEAK	NORMAL	STRONG
Total solids*	400	700	1000
Suspended solids	100	200	350
5-day BOD	100	200	400

*Includes the dissolved inorganic material from the water supply

Most states and many local utilities have established minimum design standards for sewers. The engineer must be familiar with the requirements for the area where the sewer will be installed. Tables 24.2 and 24.3 present data that may be used in the absence of any local requirement. Table 24.2 presents the requirements of Fairfax County, Virginia. Table 24.3 is taken from the sewage regulations of the Virginia Department of Health. No separate allowance is needed for infiltration if the design and construction keep this source of flow below 100 gpd/in-mile of pipe.

Variation in Sewage Flow

Sewage flow from commercial, business, and industrial establishments are generated during the operating hours. Very little flow is generated from many of these sources between late evening and early morning, as well as on weekends and holidays.

Sewage flow from residential areas is associated with activities in the homes, with peak flows occurring generally from 7 to 10 A.M. and in the evening between 6 and 10 P.M. Peak flow hours will vary somewhat for different sections of the country, as they depend on the living habits of the community. Figure 24.1 shows a typical daily variation in sewage flow for a home. The sewage flow from a home will be very close to the rate of water use. However, sewage flow in a sewer system will differ from the rate of water use in two distinct ways. The peaks in sewage flow are less pronounced because the time of concentration to a measuring point will be different for different segments of the system. For example, flow from a section of the community that is 0.25 miles away will reach the measuring point after the flow from 0.10 miles away has passed. The peak sewage flow at a treatment plant will occur some time after the peak demand on the water supply because of the flow time in the sewer. The water supply is a pressure system and a demand is placed on the source at the instant water is drawn at a faucet. Thus, peaks in flow in a sewer system occur later than what is shown in Figure 24.1 and will be less pronounced. The actual conditions depend on the size and configuration of the sewer system. Note from Figure 24.1 that water use

TABLE 24.2 Recommended Average Design Flows from the Requirements of Fairfax County, Virginia

Type of Development		Design Flow (gpd)
Residential:	General	100/person
	Single-family	370/residence
Townhouse		300/unit
Apartment unit		300/unit
Commercial:	General	2000/acre
	Motel	130/unit
	Office	30/employee
		0.20/net square feet
Industrial:	General	10,000/acre
	Warehouse*	600/acre
School Site:	General	16/student

*Varies with type of industry

drops to near zero from about midnight until about 6 A.M. Flow in a sewer system during these hours primarily will be infiltration except for some industrial and business areas.

The design engineer must design sewers to accommodate peak flows. Tables 24.2 and 24.3 provide information on daily rates of sewage flow generation. A peak factor is used to account for the differences in the average daily flow and the instantaneous flow. Nominal infiltration and inflow is accounted for by the daily flow quantities shown in Tables 24.2 and 24.3. The table values are considered to be high for properly constructed sewers. No additional allowance needs to be made for infiltration and inflow. The average daily flows shown in Tables 24.2 and 24.3 must be adjusted for peak flow rates for use in designing a sewer. The periods of minimum flow are generally not of concern in sewer design.

Some local utilities have developed or adopted from other sources regulations for establishing peak flow. Most, if not all, states also have minimum standards. Most equations for calculating a peak factor are based on population. Two such equations are given below:

$$\text{Peak Factor} = \frac{5}{p^{0.2}} \tag{24.1}$$

$$\text{Peak Factor} = 1 + \frac{14}{4 + p^{0.5}} \tag{24.2}$$

where p is the contributing population in thousands. The peak factor should be limited to a maximum value of 5 and a minimum value of 2.5.

A more useful approach in sewer design is the use of curves to establish the peak factor. This type of curve is shown in Figures 24.2 and 24.3. The average daily flow that has been calculated by using the tributary area and appropriate densities is then multiplied by the peak factor to establish the design flow for use in sewer design.

Hydraulics of Sewers

Sewage is considered to have the same hydraulic characteristics as water. It is an incompressible fluid having viscous properties similar to water. Both gravity sewers and forcemains are generally designed as circular pipes flowing full. Design practice also assumes that the flow is steady and uniform for each segment of pipe. In instances where building connections are adding flow to a segment of line, the flow at the downstream end of the segment is used for the design of the entire segment. A manhole should be installed where sewers other than building laterals connect to the line being designed. Design segments always run from manhole to manhole. Uniform flow applies when the cross-sectional area and slope of the segment are constant throughout the length. Manholes are located at all changes in slope and pipe diameter.

The flow rate is equal to the cross-sectional area of flow times the velocity at the section. This is expressed by the continuity equation,

$$Q = AV \tag{24.3}$$

where Q is the quantity of flow passing the reference point in cubic feet per second (cfs), A is the cross-sectional area of

TABLE 24.3 Recommended Design Flows as Required by the Regulations of Virginia*

Source of Flow	Design Units	Flow (gpd)
Dwellings	Per person	100
Schools with showers and cafeteria	Per person	16
Schools without showers and cafeteria	Per person	10
Boarding schools	Per person	75
Motels (rooms only)	Per room	130
Trailer courts	Per trailer	300
Restaurants	Per seat	50
Interstate or through restaurant	Per seat	180
Factories	Per person	15–35
Hospitals	Per bed	300
Nursing homes	Per bed	200
Doctors' offices	Per 1000 square feet	500
Laundromats	Per machine	500
Community colleges	Per person	15
Swimming pools	Per swimmer	10
Theaters	Per seat	5
Picnic/park areas	Per person	5
Camps with flush toilets	Per camp site	100

The above flows are considered to be adequate to include limited infiltration.
State and local utility regulations are generally considered as being minimum design conditions.
*Waterworks Regulations, Virginia Dept. of Health (1993).

flow in square feet (sq ft or ft^2), and V is the velocity of flow at the section in feet per second (fps).

If the flow is steady and uniform as generally assumed, the continuity equation is applicable and Equation 24.4 applies.

$$Q = A_1V_1 = A_2V_2 = A_3V_3 \cdots A_nV_n \tag{24.4}$$

According to the principle of conservation of mass, mass can be neither created nor destroyed. Since Q remains constant along a segment of sewer having a constant slope and diameter, the velocity remains constant.

The energy of a particle of mass is the sum of the position of the particle plus the momentum of the particle. In a homogeneous fluid, all particles in the fluid at a reference section have the same position energy (a particle at any depth has the same energy as any particle at the surface). The position energy for open channel flow is the water surface. The position energy for a closed conduit under pressure, such as a sewage forcemain, is the surface to which the liquid would rise if a vertical open tube were inserted in the top of the conduit. The pressure is indicated by the height of the water column above the center of the conduit and is known as *pressure head.* This is shown in Figure 24.4.

The momentum of a fluid particle is called *velocity head.* When a fluid moves from a stationary state to a moving state, some position energy is converted to momentum energy. This velocity head is defined as

$$H = \text{Velocity Head} = \frac{V^2}{2g} \tag{24.5}$$

where velocity head H in feet = position energy equivalent of the momentum, V is the velocity of flow in ft/sec, and g is the acceleration of gravity in ft/sec^2.

A line that connects the values of position energy at various points along a segment of sewer is called the *hydraulic*

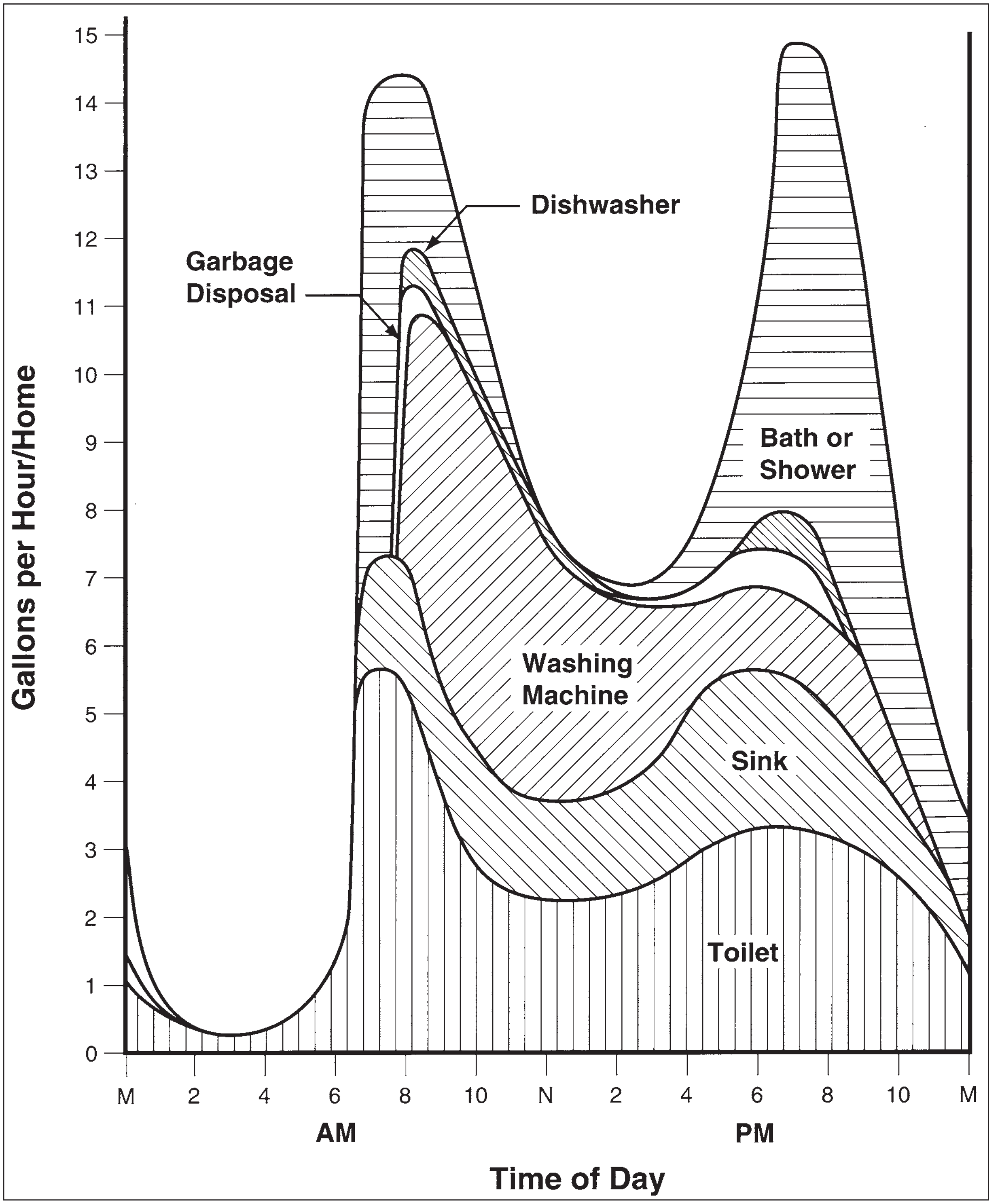

Figure 24.1 Hourly variation of sewage flow.

grade line (HGL). The line connecting the total energy values, which are the sum of the momentum (velocity head) plus position energy, is called the *energy grade line* (EGL). Under steady uniform flow conditions the two lines are parallel and separated by a distance equal to the velocity head of the flow. This is shown in Figure 24.4*a* and *b*. The slope of the two lines is the rate of energy loss or energy gradient and the drop in the lines over a length *L* is the energy loss, also known as head loss or friction loss. Under gravity flow conditions, the HGL and EGL are parallel to the sewer invert (lowest line of flow). Sewers are therefore designed and constructed on the basis of invert elevation.

A pump is a means of imparting energy to a flow. This added energy is generally expressed in feet and is the height that the energy grade line is raised by the pump. This is shown in Figure 24.5.

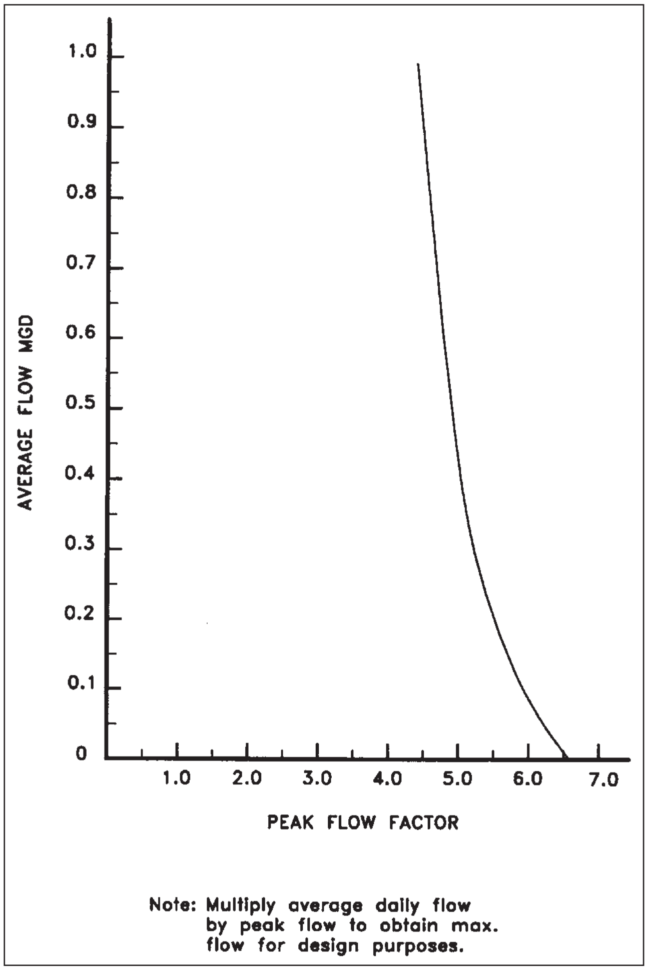

FIGURE 24.2 Peak flow curve 0–1.0 MGD.

Flow of fluid in a conduit may be defined as being laminar or turbulent. Laminar flow is flow of molecular layers of fluid where one layer is moving with respect to the adjacent layer. There is zero movement at the conduit wall under laminar flow conditions. The resistance to movement is the viscosity of the fluid. Viscosity is due to cohesion and interaction between adjacent fluid molecules. The resistance to movement is an irrecoverable energy loss that is dissipated as heat. For laminar flow, the rate of energy loss is a function of the fluid and the velocity of the fluid and not related to type of pipe material. This resistance to movement is represented by the hydraulic gradient.

The type of flow present is defined by the Reynolds number, N_R:

$$N_R = \frac{DV\rho}{\mu} \tag{24.6}$$

where D = diameter of conduit in ft, V = velocity of flow in ft/sec, ρ = fluid mass density in lb-sec^2/ft^4, and μ = shear between fluid layers in lb-sec/ft^2.

For laminar flow, the friction factor is related directly to the Reynolds number. The upper limit of the Reynolds number for laminar flow of water is 4000. As a frame of reference, water in an 8-inch pipe, which flows at a velocity of 2 fps and has a temperature of 68°F, has a Reynolds number of 50,000. This indicates that the flow is well within a turbulent flow regime, as is always the case for water and sewage flow in conduits. In sewers, the fluid particles move in a heterogeneous manner that causes a complete mixing of the fluid. This movement or turbulence is primarily created at the conduit wall by the roughness of the surface and by shear forces between the wall and the moving fluid. The conduit wall roughness and the shear forces generate turbulence vortices that move out from the wall, where they are subsequently dissipated by viscous attrition with other fluid particles. This generation and dissipation of turbulence consumes energy that is converted to heat. The energy dissipated within the flow is lost as heat. This loss is known as head loss or friction loss. As was noted for laminar flow, the slope of the HGL and EGL shows the rate of energy loss along a length of conduit. The drop in the HGL over a length of conduit is the amount of friction loss.

The roughness of the conduit interior wall is of significant importance in any hydraulic design. Pipe manufacturers

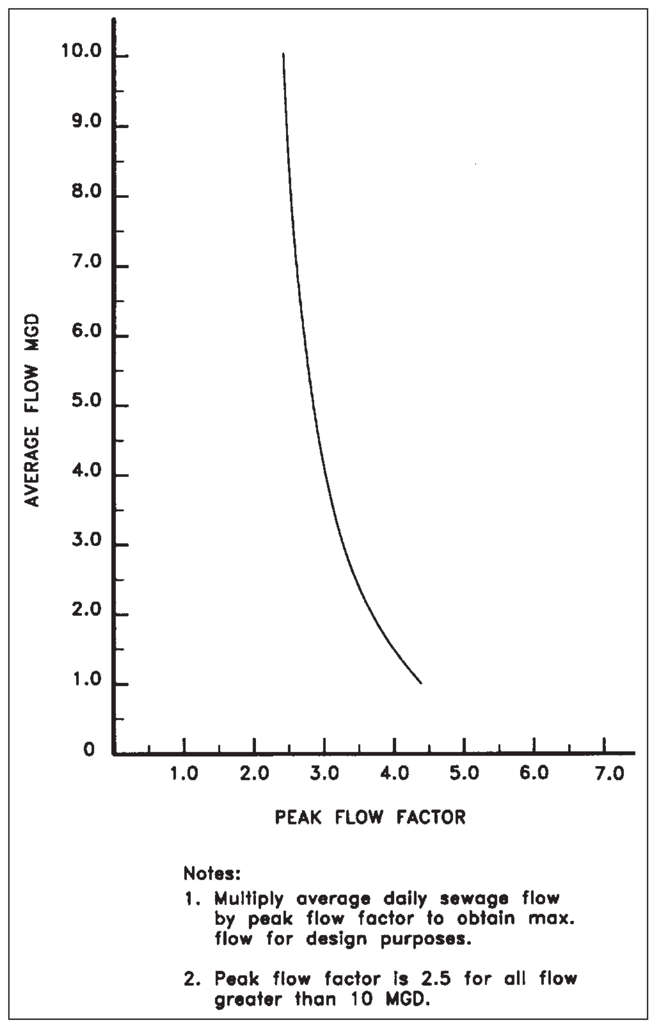

FIGURE 24.3 Peak flow curve 1.0 and greater MGD.

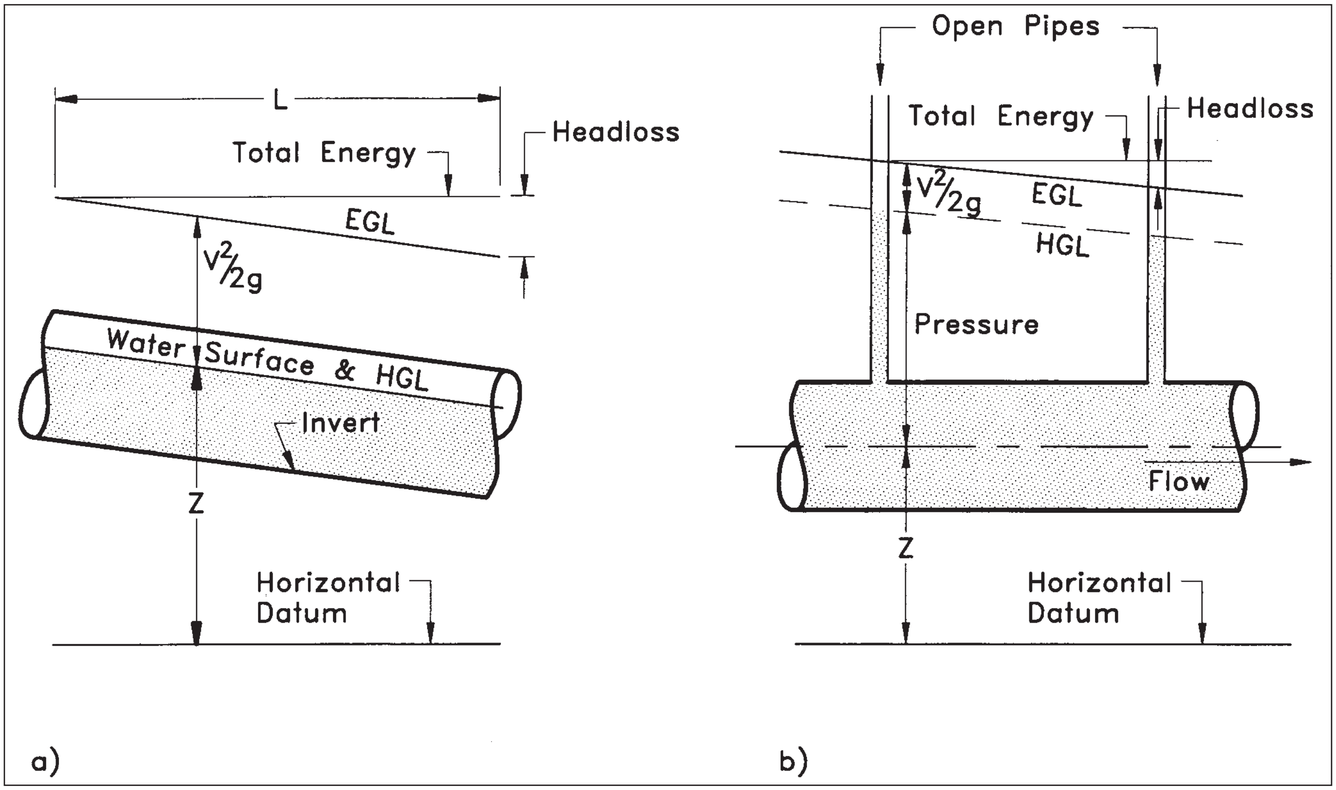

FIGURE 24.4 (*a*) HGL and EGL for gravity flow; (*b*) HGL and EGL for pressure flow.

strive to produce a pipe that has a very smooth wall surface, as this is an important item in marketing the product. A smoother pipe wall results in less turbulence generated and, hence, less energy loss in the flow. Most pipe marketed today is classified as smooth pipe.

The hydraulic design of a sewer system requires a procedure for determining the rate of energy loss. A number of equations have been developed for this purpose. Most of the equations were developed empirically from field or laboratory data, but some have been developed by dimensional analysis. Since the head loss depends on the level of turbulent vortices generated at the conduit wall, all calculations of head loss must relate to the type, height, and spacing of roughness protrusions on the pipe surface. These conduit characteristics depend on the type of pipe material selected. Pipe manufacturing is sufficiently developed to where the engineer can expect all pipe of a given material to be of uniform quality.

Furthermore, since most, if not all, pipe presently available can be considered as being smooth wall, the engineer needs to consider other characteristics when selecting the pipe material to be included in the construction. These include resistance to deterioration, ease of handling and laying, cost, and availability. The characteristics of new pipe should not be used in design because all pipe material deteriorates with age and use. There will be erosion of the surface, growth of slimes on the surface, and accumulation of solids with use and aging. Sewers should be designed to function properly at the end of the design life.

There are several equations available for determining friction loss in sewer conduits. The Manning equation is by far the most widely used. This empirical equation is accepted by all reviewing agencies. It is generally the only equation used by pipe suppliers in marketing material. Velocity is defined in open channel flow by the Manning equation as

$$V = \frac{1.486}{n} R^{2/3} S^{1/2} \tag{24.7}$$

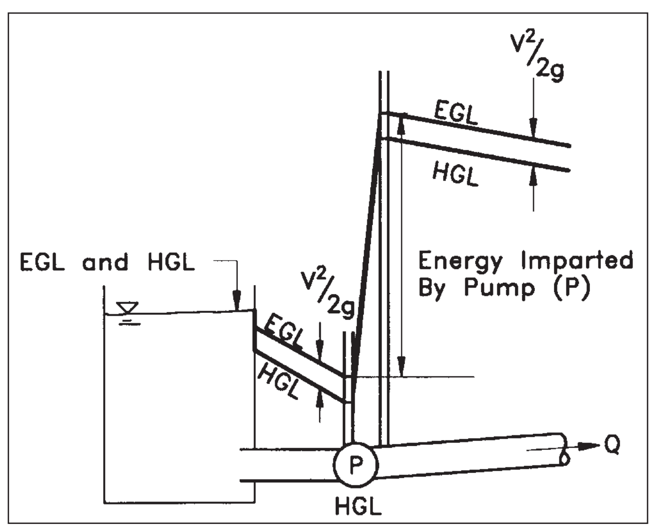

FIGURE 24.5 Change in HGL and EGL by a pump.

where V = the velocity of flow in ft/sec, n = the Manning coefficient, R = hydraulic radius = area/wetted perimeter; S = the slope of the HGL (hydraulic gradient) in ft/ft = HL/L, HL = head loss = the drop in the HGL in feet per length of sewer L.

The Manning coefficient n must be selected by the engineer. Selection is based on the type of pipe being employed in the design, giving consideration to condition of the pipe at the end of the design period.

Since $Q = AV$,

$$Q = A\left(\frac{1.486}{n} R^{2/3} S^{1/2}\right) \tag{24.8}$$

In turbulent flow, the conduit wall roughness is the principal condition that determines the intensity of turbulent vortices generated and, hence, the energy loss associated therewith. The Manning coefficient or *friction factor* is found in catalog material supplied by pipe manufacturers as well as in texts on hydraulics and related subjects. A value of 0.013 is generally used in sewer design. The Manning equation may be arranged to calculate the head loss for a length of sewer L as follows:

$$H_L = \left[\frac{VnL^{1/2}}{1.486R^{2/3}}\right] \tag{24.9}$$

Information available from pipe suppliers may indicate that a Manning n value as low as 0.009 is appropriate for their product. This would indicate that for a required velocity and capacity, the required slope of the HGL would be reduced 48 percent from that for an n value of 0.013:

$$\left[\frac{.009}{.013}\right]^2 \times 100 = 48\% \tag{24.10}$$

Or for a constant hydraulic gradient (HGL slope), the velocity and capacity would be increased 44.4 percent (0.013/0.009 = 1.444). A Manning coefficient of 0.013 is conservative for smooth wall pipe available for sewer construction. This value of n is recommended and generally used because its use allows for erosion of the pipe wall, slime buildup, and other minor obstructions to flow. These forms of pipe deterioration, resulting in reduction of capacity, occur over time. A sewer pipe material should give reliable service for at least 50 years. Other useful relationships for the Manning equation for a given diameter of conduit include:

$$Q_1/Q_2 = n_2/n_1 \tag{24.11}$$

where n is a constant.

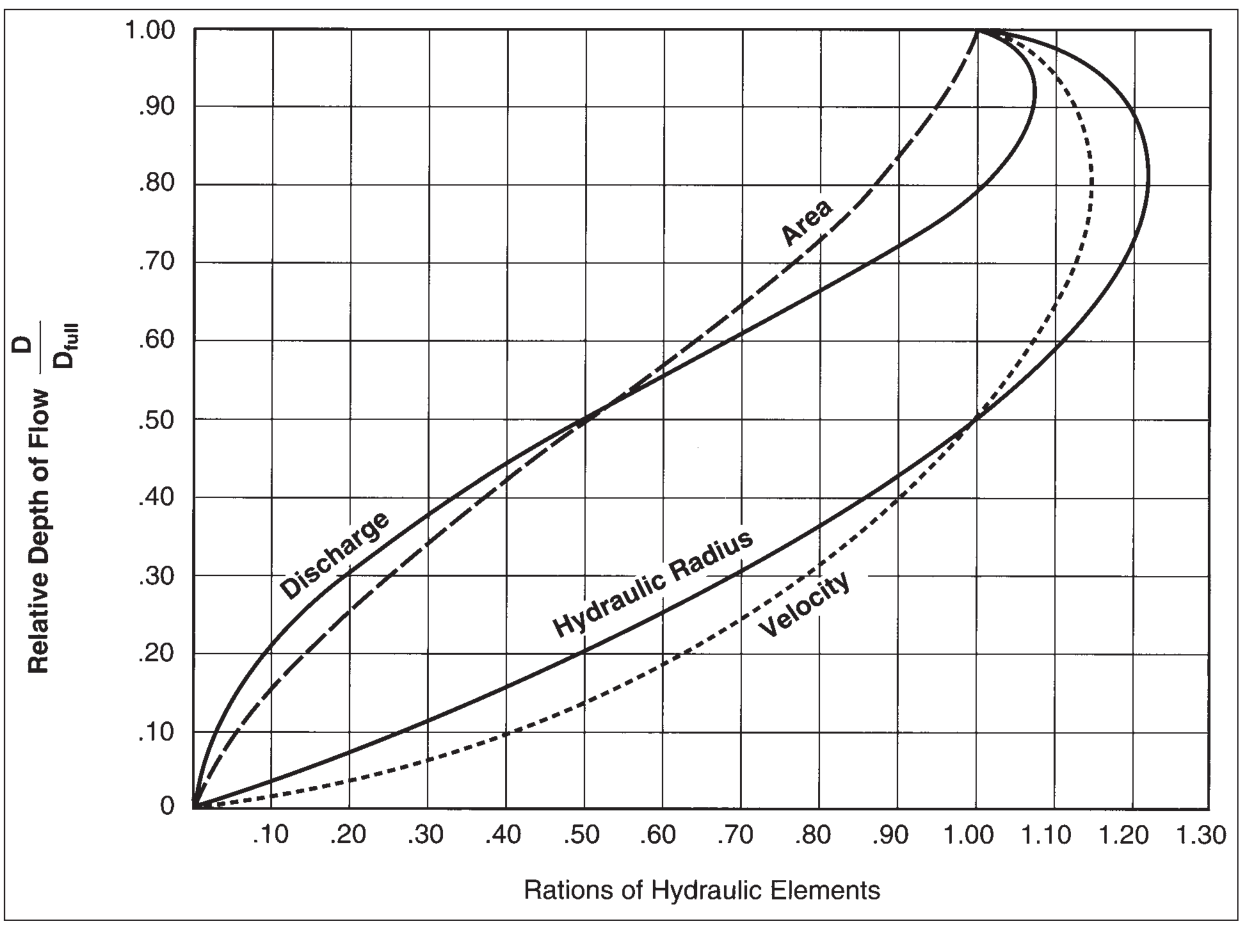

FIGURE 24.6 Nomograph of selected hydraulic elements for circular pipe flowing partially full.

$$\frac{V_1}{V_2} = \left[\frac{H_1}{H_2}\right]^2 \tag{24.12}$$

Since all pipe material used in sewer construction is essentially smooth wall, there will be little difference in the pipe roughness and, hence, in the value of *n* to be used in a design for different pipe material. The selection of the type of pipe to be used in a design and included in the contract specifications as being acceptable for use in construction should be based on the long-term serviceability of the pipe material. Serviceability factors should include expected useful life, resistance to problems with infiltration, ease of installation, resistance to corrosion and erosion, and maintenance requirements. Initial cost should not be the only determining factor.

Gravity sewers are designed to flow full at the design peak flow. Figure 24.6 presents the hydraulic properties of circular sewers for all depths of flow. As shown by the Manning equation, one of the factors influencing the velocity or capacity is the hydraulic radius *R* (area/wetted perimeter). The area of flow and the corresponding wetted perimeter do not vary uniformly with depth of flow. As shown by Fig-

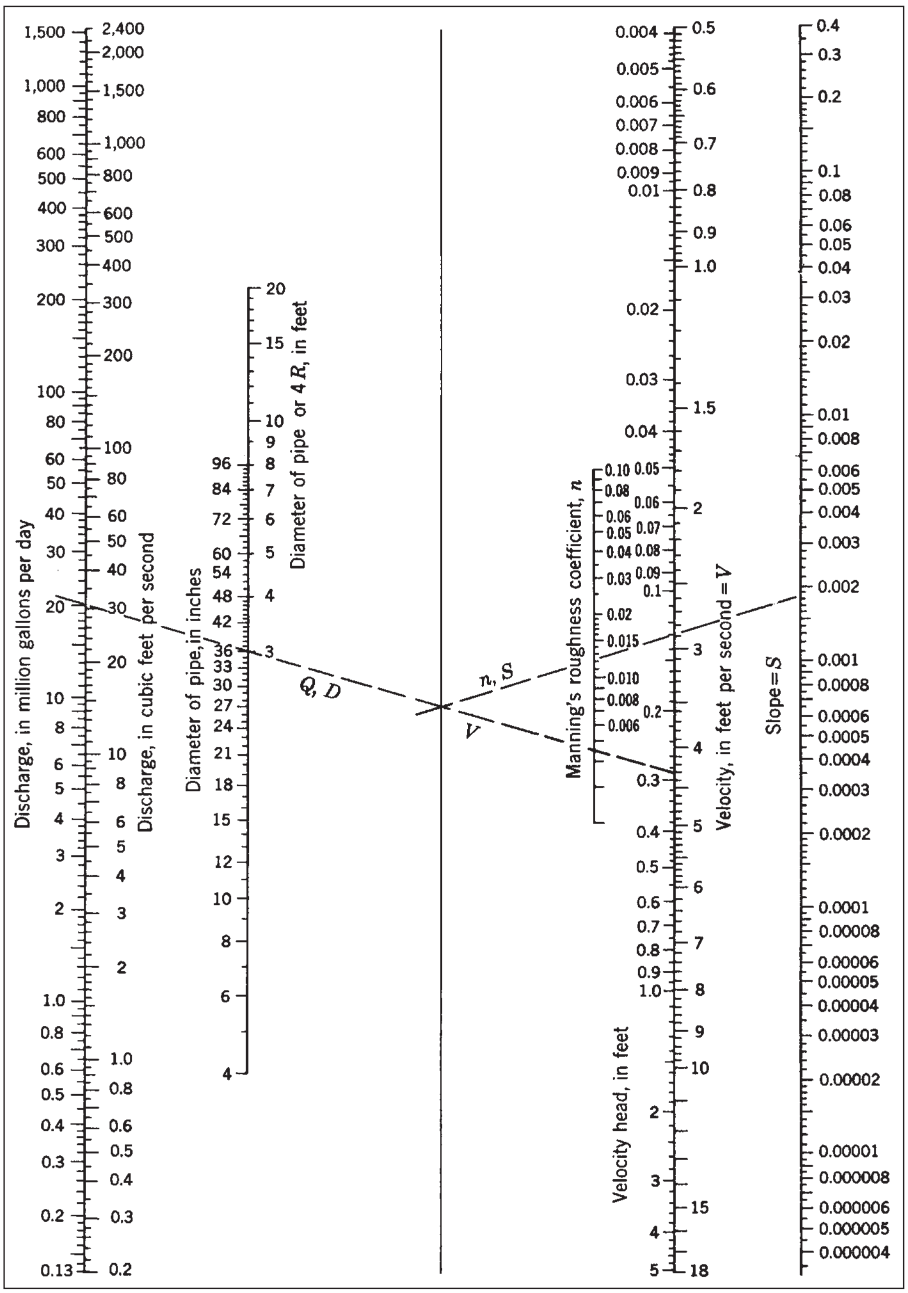

FIGURE 24.7 Nomograph for solving the Manning equation. (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York, New York)

TABLE 24.4 Common Conversion Factors

1 cfs	= 449 gpm
1 cu ft	= 7.48 gallons
1 MGD	= 1.55 cfs = 695 gpm
1 gal	= 231 cu in = 8.34 lbs
1 cu ft	= 62.4 lbs
Pressure = 62.4/144 = .433 psi per foot of water	

ure 24.6, the hydraulic radius is greatest at 0.8 of full flow depth. The velocity will also be the greatest at 0.8 of full depth. While the cross-section area of flow is maximum at full depth, flow $Q = AV$ and the maximum product of A and V is at 0.94 depth as shown by Figure 24.6. The capacity at the 0.8 depth is the same as for the full depth. Therefore, a sewer under gravity flow never flows full because the flow by natural law flows at the lower energy (energy of flow = surface elevation plus momentum). Any sewer flowing at greater than 0.8 depth is being surcharged by a downstream obstruction. Since the velocity of flow at the 0.8 depth is about 14 percent greater than at full flow, the hydraulic gradient required to achieve the equivalent full depth capacity is reduced. However, it is not common to design for the 0.8 depth conditions.

Sewers flow at less than 50 percent of full capacity most of the time. At 50 percent capacity, the depth of flow and velocity are also 50 percent of full flow conditions. Sewers should be designed to provide a minimum velocity of 2.0 to 2.25 fps at full flow. A full flow velocity of 2.25 fps ensures a scouring velocity of 1.0 fps at about 11 percent of full flow (see Figure 24.6). A scouring velocity of 1.0 fps is considered adequate to prevent deposition of solids.

Various forms of nomographs and slide rules are available for solving the Manning equation. These devices are normally used in sewer design to facilitate solving the equation. A typical nomograph is shown in Figure 24.7. The nomograph includes lines for five hydraulic elements and a pivot line. The continuity equation ($Q = AV$) may be solved by knowing two of three terms and finding the third from the nomograph without using the pivot line. The right side of the pivot line includes n, V, and S. Knowing two of the three establishes the pivot point from which knowing Q or D permits finding the other. Likewise, Q and D can be used to establish the pivot point, and knowing either n or S permits solving for the other.

EXAMPLE PROBLEM

a. What is the slope and velocity of an 8-inch pipe carrying 1 cfs?

Using Figure 24.7, knowing Q and D, find $V = 2.9$ fps.

Knowing D, Q gives pivot point, with $n = 0.013$, $S = 0.0019$.

b. What is the depth and velocity for the pipe in part (a) when the flow is 0.4 cfs?

Knowing Q/Q-full = 0.4/1.0 = 0.4 and using Figure 24.6

Depth of flow = 43% of 8 in = 3.44 in

Velocity = 95% of V-full = 2.75 fps.

There are several types of design aids in addition to the nomographs shown as Figures 24.7 and 24.29 for use in solving both the Manning and the Hazen-Williams equations. These include special nomographs and various forms of slide rules. The conventional type of nomograph shown in Figure 24.7 and the slide rule types are generally preferred by design engineers. Some pipe suppliers may provide these design aids. Some common conversion relationships for water are shown in Table 24.4. Some common design relationships from using the Manning equation are shown in Table 24.5.

TABLE 24.5 Hydraulic Elements Determined by Using Figure 24.7 and Equations 24.11 and 24.12

DIAMETER (IN.)	n	v (FPS)	s (FT/FT)	$r^{2/3}$	q (GPM)
8	0.013	2.0	0.0033	0.303	314
8	0.013	2.25	0.0042	0.303	354
8	0.010	2.0	0.0020	0.303	314
8	0.012	2.0	0.0028	0.303	314
10	0.013	2.0	0.0025	0.351	489
10	0.013	2.25	0.0031	0.351	551
12	0.013	2.0	0.0019	0.397	705
12	0.013	2.25	0.0025	0.397	793

TABLE 24.6 Class and Pressure Characteristics of Pressure PVC Pipe

PRESSURE	CLASS*	DR†	BURSTING PRESSURE	SUSTAINED
lb/in^2	100	25	535 lb/in^2	350
lb/in^2	150	18	755 lb/in^2	500
lb/in^2	200	14	985 lb/in^2	650

*The class of pipe is the limit of internal pressure to be used in design.
†DR is the ratio of the external diameter to the pipe wall thickness. For example, an 8-in DR 25 pipe has an external diameter of 9.050 in and a wall thickness of 0.362 in. Dimension ratios are controlled by manufacturing standards.

The data in Table 24.5 shows that an 8-inch sewer installed to provide a minimum velocity of 2.0 fps has a capacity of 314 gpm (0.45 mgd). This flow would be subject to a peak factor of 5 (see Figure 24.2), giving an average design flow of 63 gpm or 90,700 gpd. At a daily flow of 370 gallons per dwelling unit (see Table 24.2), this 8-inch sewer will serve 243 housing units. Likewise, a 10-inch sewer will serve 389 single-family units (note that the peak flow factor for the 10-inch line capacity of 489 gpm [0.7 mgd] is 4.8). A 12-inch sewer will serve 633 single-family units. Velocities greater than 2.0 fps and smaller *n* values will provide still greater capacity. Many developments are sewered by 8-inch sewers, and line sizes greater than 12 inches are seldom needed except for main or trunk sewers. An 8-inch-diameter sewer is considered the minimum size line in public sewer design.

Pipe Materials and Loads on Buried Conduits

The engineer now has several excellent types of pipe material available for use in sewer construction. It is important that the proper selection be made for the specific installation conditions. Pipe materials are classified as being either flexible or rigid. Pipe manufactured from materials such as concrete and vitrified clay are classified as rigid wall pipe. A deflection of the wall of a rigid wall pipe will result in pipe failure. The most common type of flexible pipe is polyvinyl chloride (PVC), which is widely used in both sewer and water line construction. A limited wall deflection of a flexible wall pipe does not reduce the serviceability of the conduit. Ductile iron and high-density polyethylene are also flexible pipe materials.

Rigid pipe is classified on the basis of bursting strength, and for pressure pipe the internal pressure rating is also included. The bursting strength is established by standard tests and is provided by the manufacturer in pounds of external vertical force per foot of pipe. It is listed as the three-edge bearing strength that reflects the type of standard test procedure. Pipe is designed to withstand both the internal pressure and the external loading simultaneously. The manufactured wall thickness is adjusted to provide the required strength. The engineer should have library catalog data available for the types of pipe material being considered for incorporation into a design. The strength of rigid pressure pipe will be shown by pipe class such as class 150, 200, and so on.

Gravity flow sewer pipe is designed to withstand external pressure loadings. Rigid wall pipe is manufactured in several wall strengths as may be required for design conditions. For example, pipe classes are designated as 1500, 2400, 3300,

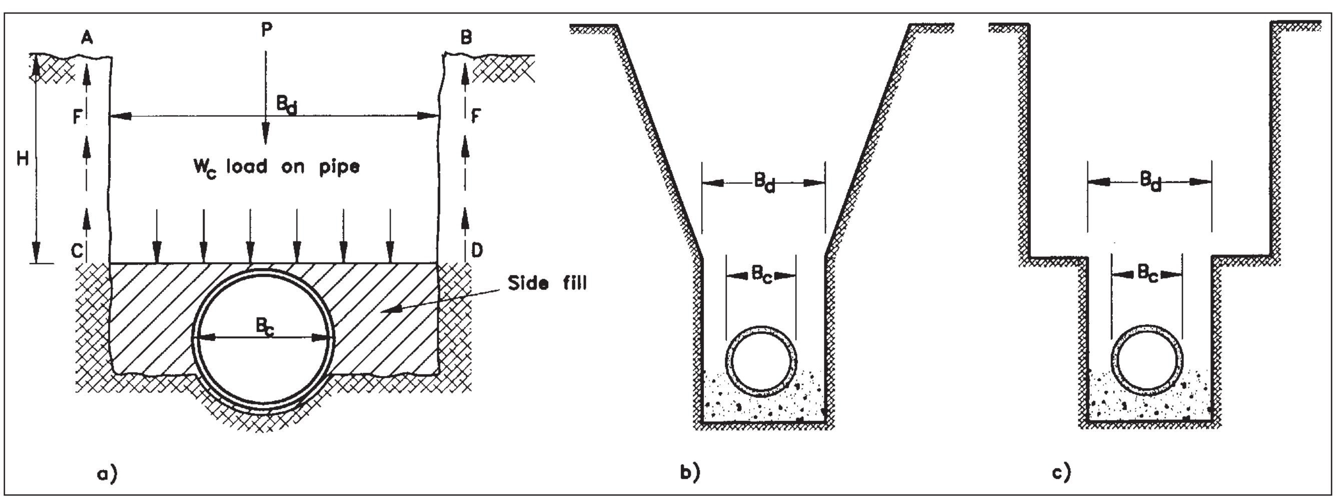

FIGURE 24.8 Typical trench conditions for a rigid conduit. (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York, New York)

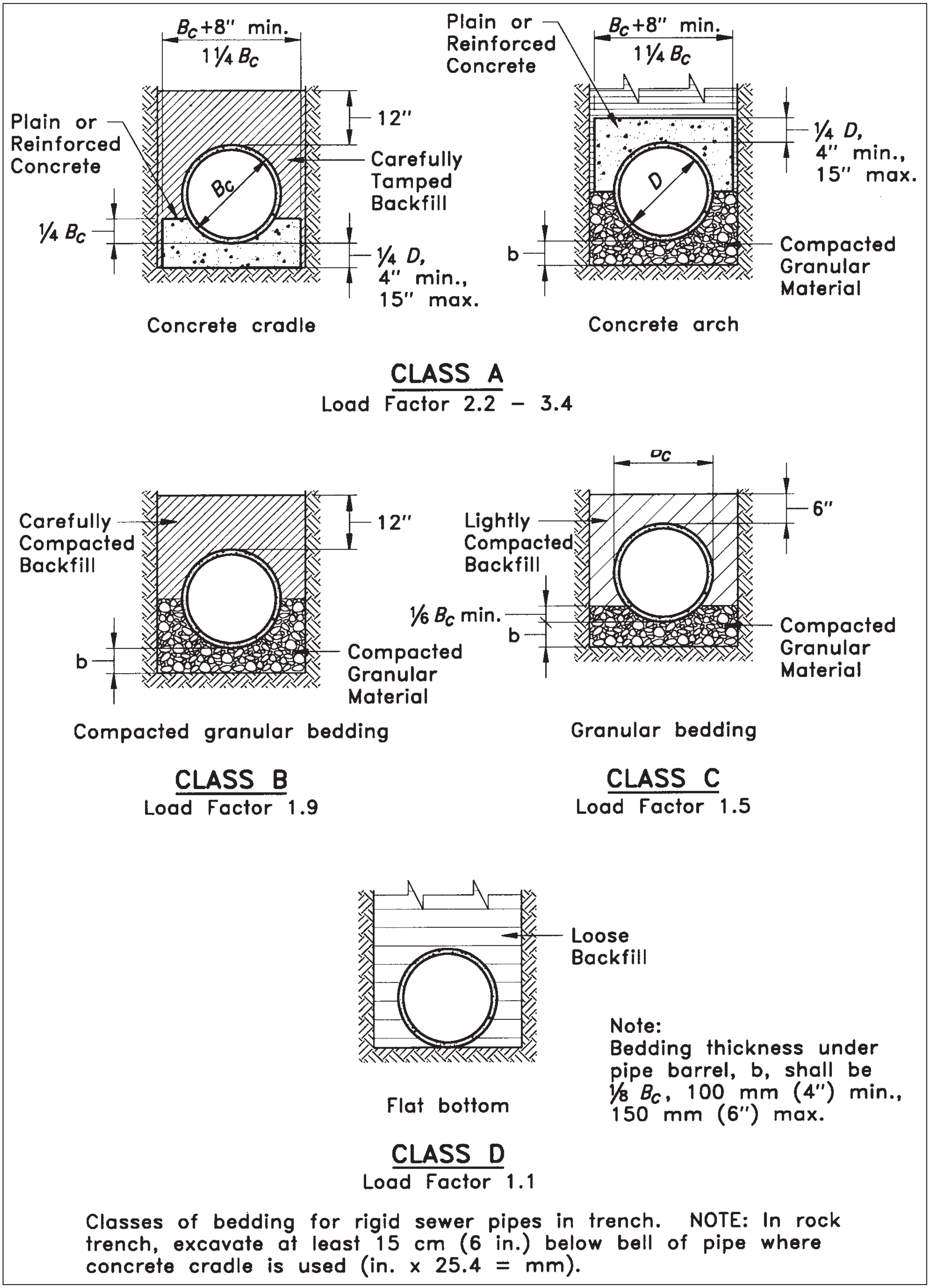

FIGURE 24.9 Bedding methods for trench conduits. (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York, New York)

TABLE 24.7 Embedment Materials Classification System

				Percentage Passing Sieve Sizes			Atterberg Limits	Coefficients	
Class	Type	Soil Group Symbol D 2487	Description	1½ in. (40 mm)	No. 4 (4.75 mm)	No. 200 (0.075 mm)	LL PL	Uniformity C_u	Curvature C_c
IA	Manufactured aggregates: open-graded, clean	None	Angular, crushed stone or rock, crushed gravel, broken coral, crushed slag, cinders or shells; large void content, contain little or no fines	100%	≤10%	<5%	Nonplastic		
IB	Manufactured, processed aggregates; dense-graded,	None clean	Angular, crushed stone (or other Class 1A materials) and stone/sand mixtures with gradations selected to minimize migration of adjacent soils; contain little or no fines	100%	≤50%	<5%	Nonplastic		
II	Coarse-grained soils, clean	GW	Well-graded gravels and gravel-sand mixtures; little or no fines	100%	<50% of "Coarse Fraction"	<5%	Nonplastic	>4	1–3
		GP	Poorly graded gravels and gravel-sand mixtures; little or no fines					<4	<1 or >3
		SW	Well-graded sands and gravelly sands; little or no fines		>50% of "Coarse Fraction"			>6	1–3
		SP	Poorly graded sands and gravelly sands; little or no fines					<6	<1 or >3
	Coarse-grained soils, borderline clean to w/fines	e.g., GW-GC, SP-SM	Sands and gravels which are borderline between clean and with fines	100%	Varies	5%–12%	Nonplastic	Same as for GW, GP, SW, and SP	

(*Continued*)

TABLE 24.7 (Continued)

				Percentage Passing Sieve Sizes			Atterberg Limits		Coefficients	
Class	Type	Soil Group Symbol D 2487	Description	1½ in. (40 mm)	No. 4 (4.75 mm)	No. 200 (0.075 mm)	LL	PL	Uniformity C_u	Curvature C_c
III	Coarse-grained soils with fines	GM	Silty gravels, gravel-sand-silt mixtures	100%	<50% of "Coarse Fraction"	12% to 50%		<4 or <"A" Line		
		GC	Clayey gravels, gravel-sand-clay mixtures					<7 and >"A" Line		
		SM	Silty sands, sand-silt mixtures		>50% of "Coarse Fraction"			>4 or <"A" Line		
		SC	Clayey sands, sand-clay mixtures					>7 and >"A" Line		
IVA[A]	Fine-grained soils (inorganic)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, silts with slight plasticity	100%	100%	>50%	<50%	<4 or <"A" Line		
		CL	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays					>7 and >"A" Line		
IVB	Fine-grained soils (inorganic)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	100%	100%	>50%	>50	<"A" Line		
		CH	Inorganic clays of high plasticity, fat clays					>"A" Line		
V	Organic soils	OL	Organic silts and organic silty clays of low plasticity	100%	100%	>50%	<50	<4 or <"A" Line		
		OH	Organic clays of medium to high plasticity, organic silts							
	Highly organic	PT	Peat and other high organic soils				>50	<"A" Line		

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TABLE 24.8 Characteristics of the Most Commonly Used Sizes of SDR-35 Pipe

NOMINAL SIZE LAYING LENGTH (IN)	EXTERNAL DIAMETER (IN)	WALL THICKNESS (IN)	WEIGHT (LB/FT)	LAYING LENGTH
8	8.4	0.24	4.42	20
10	10.5	0.300	6.93	20
12	12.5	0.36	9.91	20
15	15.3	0.43	14.90	12.5

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4000, and 5000. The class strengths represent the design crushing strength in pounds per linear foot of pipe.

Flexible wall pipe is classified by the ratio of the external diameter to the wall thickness. This is expressed as dimension ratio (DR) or standard dimension ratio (SDR). Since limited deflection of the pipe can be tolerated, the strength is expressed in terms of the force required to cause a defined deflection. Pressure flexible pipe is designated by pressure class. A PVC pressure pipe manufactured by Johns-Manville under the name Blue Brute is available in the three classes shown in Table 24.6.

In Table 24.6, a DR-25 pipe has a design pressure rating of 100 lb/in^2, while the sustained pressure strength is 350 lb/in^2. This difference provides for surges in pressure, known as water hammer, and a safety factor against failure. For example, a design pressure condition of 100 lb/in^2 plus a surge maximum of 100 lb/in^2 above the design pressure provide a safety factor against failure of 1.75 (350/200 = 1.75).

Buried Conduits

The theory for loads on buried conduits states that the load on a buried conduit is equal to the weight of the prism of earth directly over it, plus or minus the frictional shearing forces transferred to that prism by adjacent prisms of earth—the magnitude and direction of these frictional forces being a function of the relative settlement between the prisms. The equation for calculating the load on a rigid buried conduit as developed by Marston at the Iowa Engineering Experiment Station in 1913 states:

$$W_c = C_D w B^2{}_D \tag{24.13}$$

where W_c (lbs/ft) is the load acting on the conduit after settlement has taken place; C_D is a dimensionless coefficient related to the diameter of the conduit, the width of the trench, and the characteristics of the fill material and the pipe bedding conditions (C_D is obtained from tables or charts); w is the unit weight of the fill material in lb/ft^3 (normal earth material may be taken as 130 lbs/ft^3), and B_D is the width of the trench in feet (note that load increases as the square of B).

The engineering design can mitigate the load on the conduit by keeping the trench as narrow as practical (the load varies as the square of the width) and by requiring good bedding and backfill conditions. Figure 24.8 shows the type of forces affecting the load on the conduit.

In Figure 24.8*a* the load on the conduit is related to the weight of the soil in the area ABDC. The upward shearing forces F reduce the load on the conduit. If the fill below the top of the conduit is not well compacted, the load on the conduit is increased as the material settles. It is sometimes necessary to slope the ditch walls for construction safety and convenience. Figures 24.8*b* and *c* show two construction means of widening the trench without increasing the earth

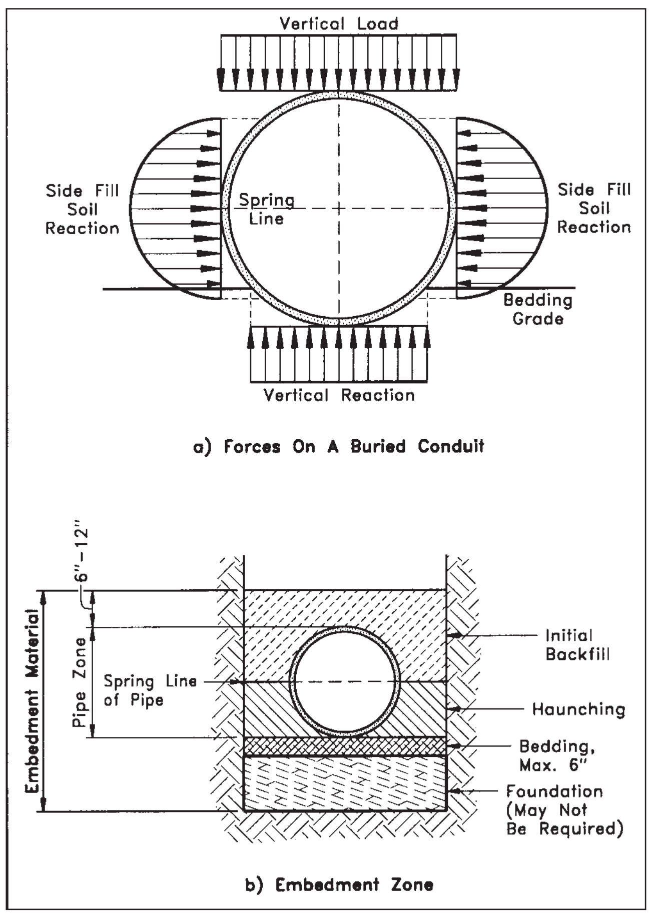


FIGURE 24.10 Forces on a buried conduit (a); Embedment zones (b). (Reprinted with permission from College of Engineering, Utah State University)

load on the conduit. It is important to keep the trench as narrow as practical from the top of the pipe to the bottom of the trench because the load on the conduit increases as the square of the width B. B is taken as the width of the trench at the top of the conduit.

There are four classes of bedding, as shown in Figure 24.9. The engineer is required to select a bedding type based on field conditions. Classes B or C are suitable except where unusual loading conditions exist. Class D bedding is used only for small-diameter pipe, not for sewer line construction.

Class A–Concrete Cradle: Bedding in which the lower part of the exterior of the conduit is set in a plain or reinforced concrete foundation of suitable thickness extending upward on each side for not less than 25 percent of the height of the conduit.

Class B–First Class: Bedding where the conduit is set on fine granular materials in an earth foundation shaped to conform to the lower part of the conduit exterior for a width of at least 60 percent of its exterior diameter. The trench is then backfilled with granular materials, hand placed, and tamped in 6-in layers to fill completely all spaces under and adjacent to the conduit for a distance of at least 1 ft above the top of the conduit.

Class C–Ordinary: Bedding in which the conduit is placed with ordinary care in an earth foundation shaped to fit the lower part of the conduit to the spring line. The ditch is then backfilled with granular materials, shovel placed, and tamped to fill all spaces to a height of at least ½ ft above the top of the conduit.

Class D–Impermissible: Bedding in which little or no care is exercised to shape the foundation to fit the pipe.

The engineer also should specify the embedment material to be used with the installation of the conduit. This information should be included in the specifications and also shown on the plans. Table 24.7 provides information on the standard material classification system. The soil types are standard under the United Soil Classification System (ASTM D2487). The materials are grouped into categories that are considered to be most suitable for embedment use.

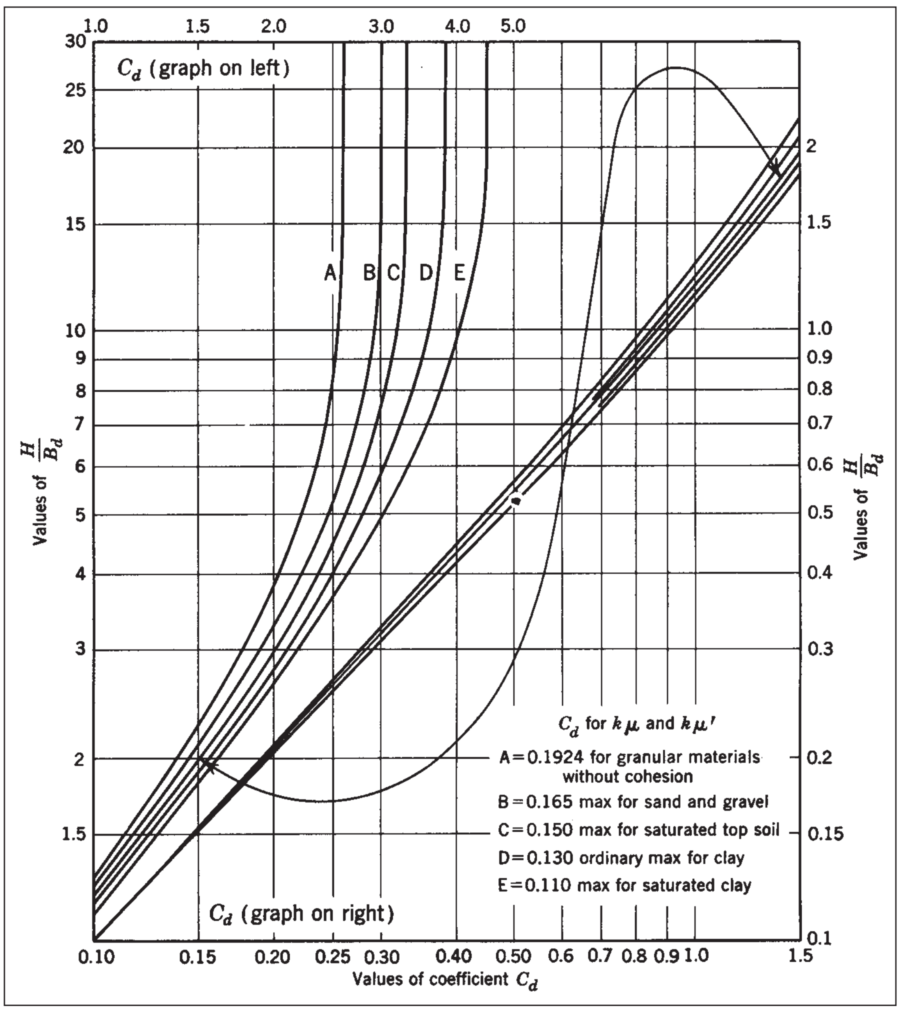


FIGURE 24.11 Values of C_d for trench conditions. (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York, New York.

Flexible Conduits

Flexible sewer pipe, such as PVC, is designated by the standard dimension ratio as noted for flexible pressure pipe. The most often used sewer flexible pipe is SDR-35. Heavier-wall-thickness pipe, such as DR-21, are available for use where required to meet laying conditions. Data for the more common sizes of SDR-35 pipe is given in Table 24.8.

A flexible pipe having a DR greater than 35 should not normally be considered for sewer construction. The smaller wall thickness associated with the greater DR values may not provide long-term reliability.

A flexible pipe yields under an external load by deflecting. This deflection results in a shortening of the vertical diameter because of the load on the pipe from the fill material on top of the pipe. Excessive deflection results in failure through openings at the joints and a reduction of internal area for flow even though the pipe has not collapsed. In conservative design the allowable deflection is limited to 5 percent, although deflections up to 7.5 percent are used in design.

Figure 24.10 gives an illustration of the embedment zones and the forces acting on a buried flexible pipe. As shown in Figure 24.10*a*, the vertical load on the pipe is distributed evenly over the width of the pipe. The vertical reaction acting on the bottom of the pipe is distributed evenly over the width of the pipe subtended by the bedding angle. The parabolically distributed side forces act through the middle 100 degrees of the pipe. The maximum pressure, found at the pipe's springline, is passive resistance of the backfill around the pipe. Using suitable backfill material and proper compaction is very important in establishing the field strength of a flexible conduit, as the vertical diameter cannot shorten, or deflect, without a corresponding lengthening on the horizontal diameter. The embedment zones, as shown in Figure 24.10*b*, illustrate the proper bedding conditions and the common nomenclature associated with pipe installation.

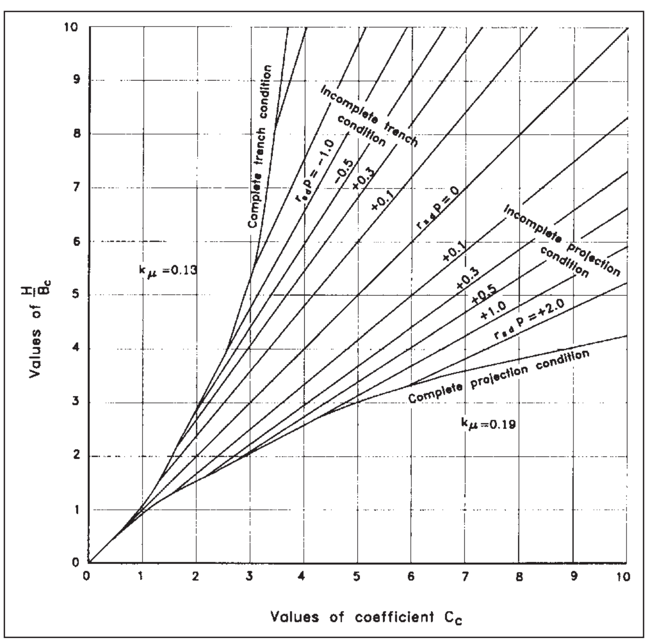


FIGURE 24.12 Values of C_c for positive projection conduits. (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York, New York)

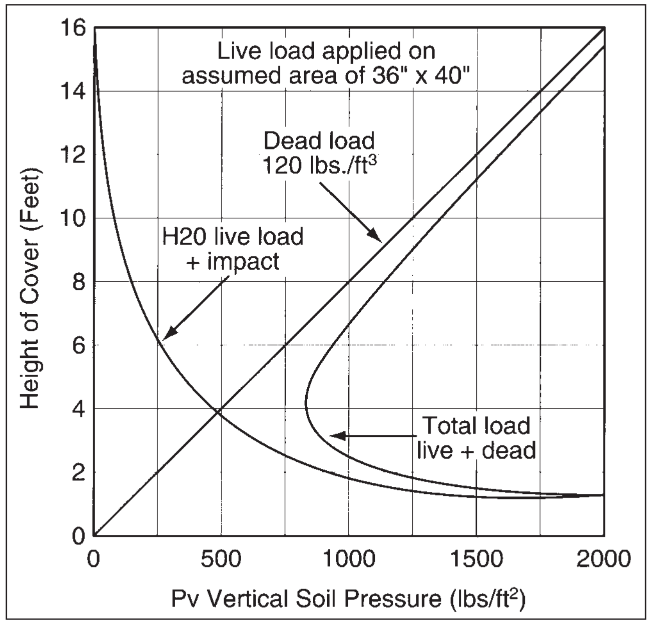


FIGURE 24.13 Total pipe load—H20 live load plus dead load. (Source: *Handbook of Steel Drainage and Highway Construction Products,* reprinted with permission from McGraw-Hill)

Zone Terminology

Foundation: A foundation is required when the trench bottom is unstable. Any foundation that will provide continuous support without causing loss of grade or flexural deformation is suitable.

Bedding: The bedding directly underneath the pipe is required to bring the trench to grade. The bedding should be shaped to fit the conduit with a depression formed to receive the bell of the pipe so the pipe rests on the pipe barrel for its entire length. The labor to manually shape the bottom of the trench is expensive, so it is common practice to overexcavate a couple of inches and bring the trench bedding to grade with granular material such as crushed stone. The bedding should be firm to support the pipe.

Haunching: The haunching area is most important in providing good pipe support. The contractor must insure that the haunch area under the pipe is completely filled and that the area is compacted to the specified density. Most of the pipe support comes from this area.

Initial Backfill: The initial backfill begins at the springline and continues to 6 in or 12 in above the top of the conduit. When the conduit is properly installed to this level, problems related to pipe bedding should not develop. If proper compaction is not provided above this point, there may be problems with surface settling for some time.

TABLE 24.9 Maximum Long-term Deflections* in % of SDR 35 Pipe

ASTM Embedment Material Classification		Density Proctor AASHTO T-99	Height of Cover (Feet)													
			3	5	8	10	12	14	16	18	20	22	24	26	28	30
Manufactured granular angular	CLASS I		0.2	0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
Clean sand and gravel	CLASS II	90%	0.2	0.3	0.5	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.6	1.7	1.8	2.0
		80%	0.9	1.4	2.3	3.2	3.6	4.1	5.0	5.5	6.0	6.4	7.3	7.7	8.2	9.1
Sand and gravel with fines	CLASS III	90%	0.2	0.4	0.6	0.8	0.9	1.1	1.2	1.4	1.6	1.7	1.9	2.1	2.2	2.3
		85%	0.7	0.9	1.7	2.2	2.6	3.0	3.5	3.9	4.3	4.8	5.2	5.6	6.0	6.5
		75%	1.1	1.8	2.9	3.8	4.5	5.5	6.8	8.5	9.9	11.3	12.7	14.1	15.5	16.8
		65%	1.3	2.4	3.6	4.7	5.5	6.8	8.5	9.6	11.4	13.0	14.5	16.0	17.3	18.0
Silt and clay	CLASS IV	85%	0.65	0.9	1.7	2.2	2.6	3.0	3.5	3.9	4.3	4.8	5.2	5.6	6.0	6.5
		75%	1.3	2.3	3.3	4.3	5.0	6.5	7.8	9.5	10.6	12.2	13.5	15.0	16.3	17.0
		65%	1.3	2.4	3.6	4.7	5.5	8.0	10.5	12.5	15.0	17.6	20.0	22.0	24.0	26.0
Organic soils and peat	CLASS V		THIS SOIL CLASS NOT RECOMMENDED													

*Deflection is the percent reduction of the vertical diameter.
(Reprinted with permission from College of Engineering, Utah State University.)

The equation for determining the load on flexible conduits installed under a ditch condition, as developed by Marston, is:

$$W_c = C_D w B_D B_C \tag{24.14}$$

where W_c = external earth load on the conduit in pounds per linear foot, C_D = load coefficient for conduits installed in a trench condition (suitable charts are available for determining C_D, as shown in Figure 24.11), w = unit weight of backfill material in pounds per ft^3, B_D = width of the trench at the top of the conduit in feet, and B_C = external horizontal diameter of the conduit in feet.

The ratio of the external load for rigid versus flexible conduits is given by the ratio of Equation 24.13 to Equation 24.14, and is equal to $W_D/W_C = B_D/B_C$. This ratio shows that the load on a flexible conduit is significantly less than that for a rigid conduit installed under the same conditions (C_D = constant). This is because the load on a buried conduit is modified by the response of the conduit. A minor deflection of the flexible conduit can materially reduce the load if the conduit has been properly installed, which means the conduit has been placed in a relatively narrow trench and properly bedded and the backfill has been properly compacted above the conduit. Where the trench is sufficiently narrow, a part of the backfill load is transferred to the sides of the trench by shear action. Where the backfill is not properly placed and compacted to the top of the conduit, the consolidation of the fill material alongside the conduit results in an additional load being placed on the conduit as the fill settles. The specifications and field inspection must ensure that the trench width is limited, the pipe is properly bedded, and the backfill is properly placed and compacted to 6 inches above the top of the conduit. This will mitigate problems with failing conduits and infiltration.

While it is desirable to keep the trench width as narrow as possible, it is necessary to provide space for the workers to install the pipe. Also, room must be allowed for a trench box. Normally a 42-inch trench is suitable for sewer diameters up to 16 inches. Above 16 inches, the trench width should be the pipe diameter plus 24 inches, allowing 12 inches on each side of the pipe for the trench box and the workers. Figure 24.11 provides a graphical means for determining C_d for use in Equations 24.13 and 24.14. H is the

TABLE 24.10 Air Test Table

LENGTH OF LINE IN FEET	PIPE DIAMETER												
	4″*	**6″**	**8″**	**10″**	**12″**	**15″**	**18″**	**21″**	**24″**	**27″**	**30″**	**33″**	**36″**
25	2.9	4.2	5.7	7.1	8.5	10.6	12.7	14.8	17.0	19.2	21.2	23.3	25.5
50												23.3	25.5
75										19.2	21.2	24.3	28.9
100								14.8	17.0	21.6	26.8	32.2	38.5
125							12.7	16.3	21.2	27.0	33.3	40.1	48.2
150						10.6	14.3	19.6	25.5	32.6	40.1	48.3	57.6
175						11.6	16.7	22.8	29.7	37.9	46.7	56.2	67.3
200					8.5	13.3	19.1	26.1	34.0	43.3	53.5	64.4	77.0
225				7.1	9.5	15.0	21.5	29.4	38.2	48.7	60.1	72.3	86.7
250				7.4	10.6	16.7	24.0	32.6	42.5	54.0	66.9	80.5	96.1
275				8.1	11.7	18.3	26.3	35.9	46.7	59.6	73.5	88.4	105.8
300			5.7	8.9	12.7	20.0	28.7	39.1	51.0	65.0	80.3	96.6	115.5
350			6.6	10.4	14.9	23.4	33.4	45.7	59.5	75.7	93.7	112.7	134.6
400		4.2	7.6	11.9	17.0	26.7	38.2	52.2	68.0	86.6	107.1	128.8	154.0
450		4.8	8.5	13.4	19.1	30.0	43.0	58.7	76.5	97.4	120.5	144.9	173.1
500	2.8	5.3	9.5	14.9	21.2	33.3	47.8	65.3	85.0	108.3	133.9	161.0	192.5

*When testing 4-in house laterals with sewer main, add 2.8 minutes to test time.

height of the fill from the top of the conduit to the surface. Other parameters are as defined previously.

An embankment condition, as opposed to a trench condition, exists when a conduit is installed in a trench that is so wide that the sides of the trench have no effect on the load to the conduit. A transition width is where there is no additional load imposed on the conduit, as the ditch becomes wider. This transition width depends on the depth and diameter of the conduit. Conduits installed in trenches wider than the transition widths are said to be installed in a *projection condition.* Conduits should not be installed in this manner. Even in fill, the fill should be placed and a trench excavated for the conduit. However, where it may be found necessary to install a conduit under a projection condition, Marston has provided the following equation for determining the resulting load to the conduit:

$$W_c = C_c w B_c^2 \qquad (24.15)$$

where C_c is the coefficient for a projection condition (replaces C_d as shown for trench condition) and w and B_c are defined above for Equations 24.13 and 24.14. A suitable chart has been developed for use in determining C_c as shown by Figure 24.12.

Superimposed Loads

Superimposed loads and live loads may come from vehicle traffic where the conduit is located in the street or from storing of material on the surface, such as in a lumber yard. Figure 24.13 shows the general effect of the combined trench earth load plus the superimposed load. It is important to note that for pipe cover greater than 8 ft, the superimposed load is generally of little significance. In general, sewers located in a roadway pavement area should have at least 6 ft of cover over the top of the pipe. Sewers not located in roadways should be installed below the freeze depth or a minimum of 3 ft. Figure 24.13 is for an H20 loading, which is what is generally used in practice (rear axle carries 16 tons). The impact of the superimposed load must also be considered, but impact is not considered significant where the conduit has at least 3 ft of cover. The superimposed load is added to the dead load (trench backfill load). Tables and equations for calculating superim-

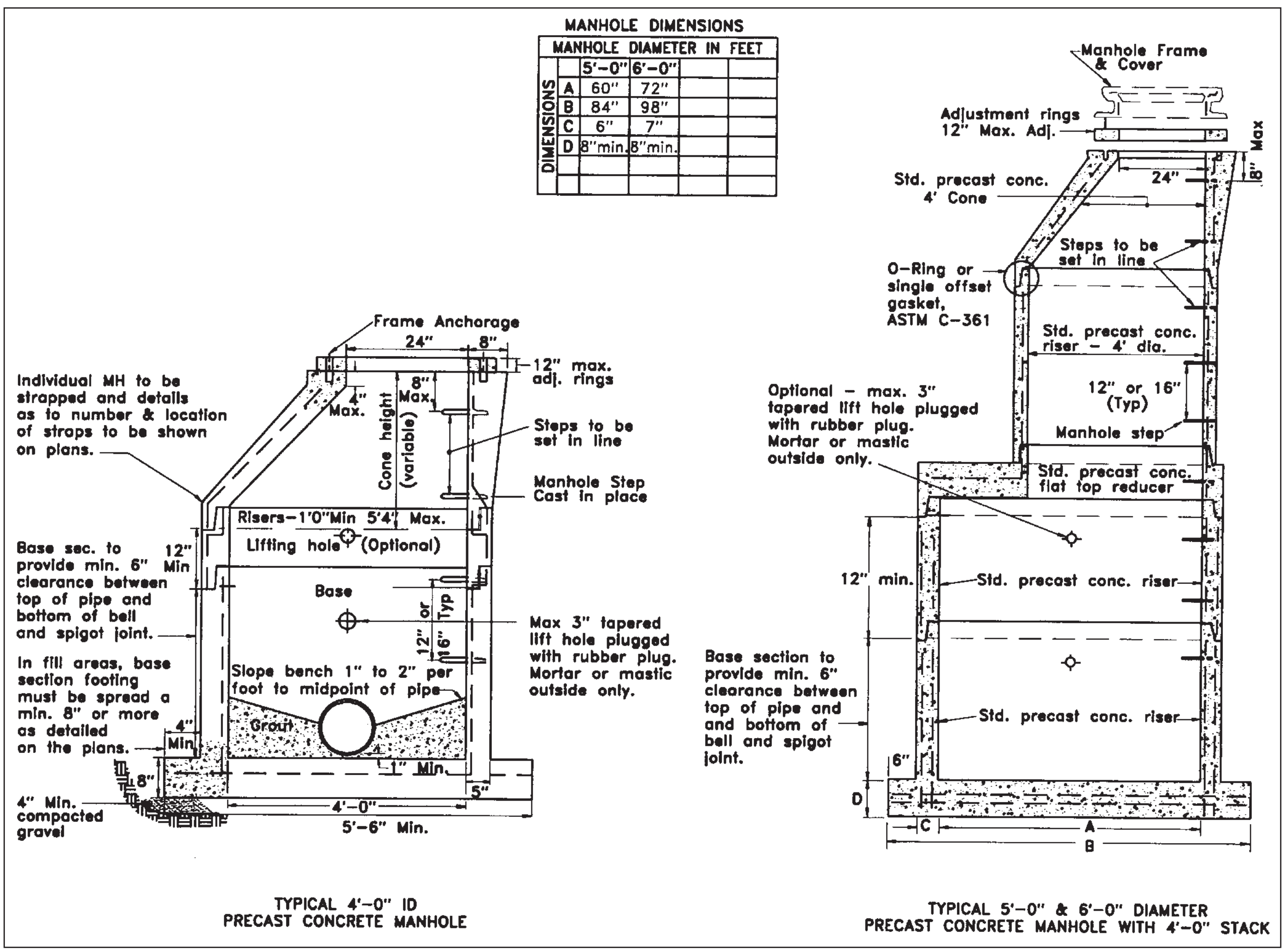


FIGURE 24.14 Typical precast manhole design. (*Handbook of Steel Drainage and Highway Construction Products,* reprinted with permission from McGraw-Hill)

posed loads are found in reference books and pipe supplier catalogs.

While it is important for the engineer to have an understanding of the principles related to loads on buried conduits, it is not always practical to attempt to calculate the load by Equation 24.13. The end result from calculating loads will be no more reliable than the assumptions about field conditions. Soil conditions vary from location to location, and even an experienced soil engineer would find it necessary to conduct extensive field studies to make the input parameters more reliable than engineering judgment and the data available from tables.

Pipe is manufactured to standards that include safety factors for the broad classes of embedment conditions presented before. Pipe suppliers provide tables or curves for use in design such as shown in Table 24.9. This table shows the deflection of SDR pipe under the indicated installed condition. As shown by the data, pipe deflections can be held to less than 5 percent by providing proper embedment.

Data similar to that provided in Table 24.9 for SDR 35 pipe is available from all suppliers of both sewer and pressure pipe. Standard design go/no go devices as well as electronic deflectometers are available for measuring the deflection of sewer pipe after installation. The engineer should include a requirement in the specifications for this measurement to be made after the backfill load has stabilized.

Air Testing

The contract specifications should require that a leakage test be performed to verify the watertightness of the sewer. An air test is generally required for this purpose, although an older water test may be used. The air test is easier to conduct and gives good results. The section of line to be tested is plugged and pumped up to a pressure of 4 lb/in^2 plus 0.433 lb/in^2 for each foot of ground water over the conduit (pressure should not exceed 9 lb/in^2). The pressure is allowed to stabilize to the sewer temperature. Pressure drop is then timed from 3.5 lb/in^2 to 3.0 lb/in^2 (0.433 lb/in^2 times the feet of ground water over the pipe must be added to these numbers). Acceptable time limits for the 0.5 lb/in^2 pressure drop are shown in Table 24.10.

Pipe Joints

Manufactured rubber compression joints should be used in sewer construction unless there are unusual conditions. The joint should be free of debris and the rubber gasket lubricated prior to installing the pipe.

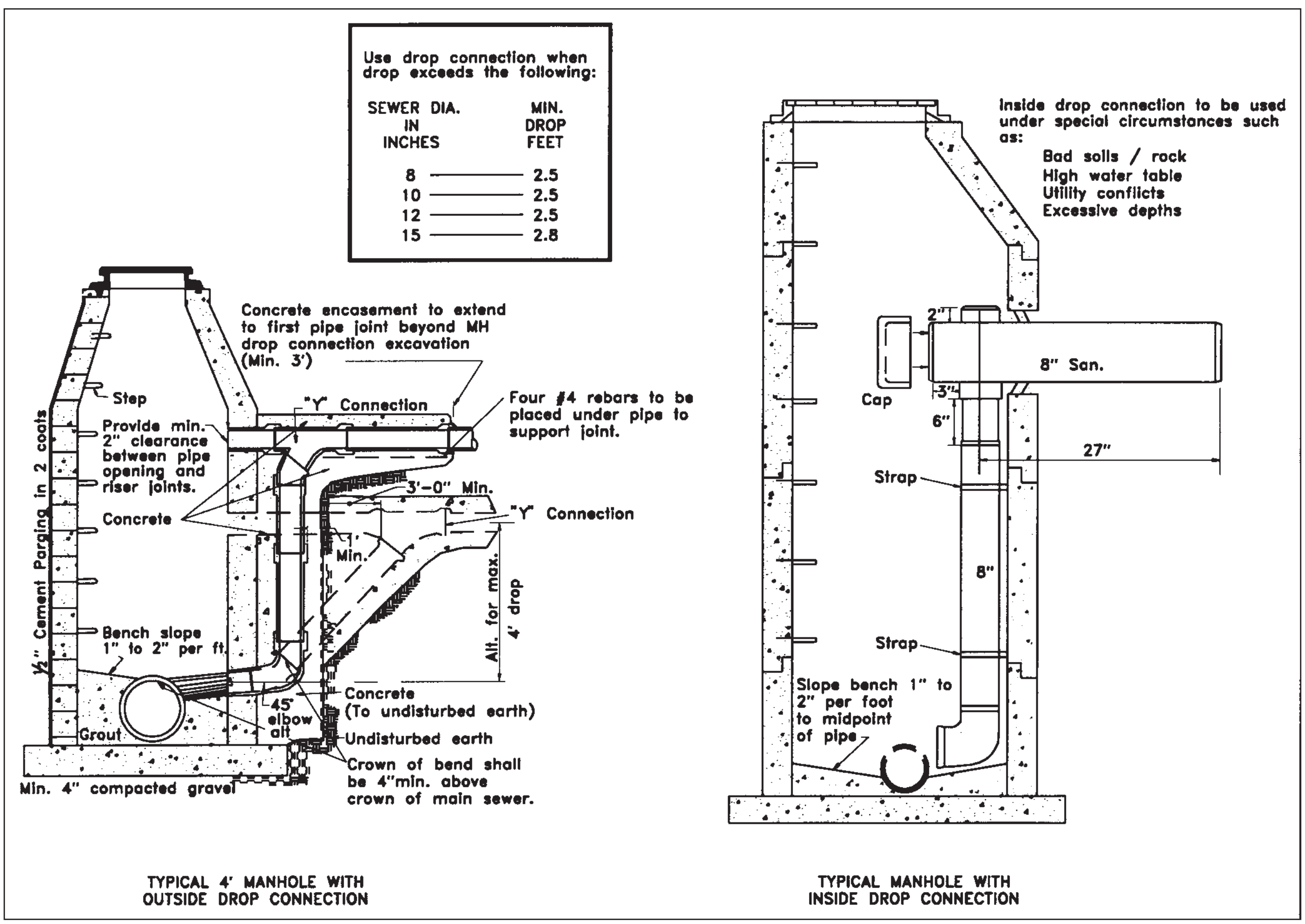


Figure 24.15 Typical drop manhole design.

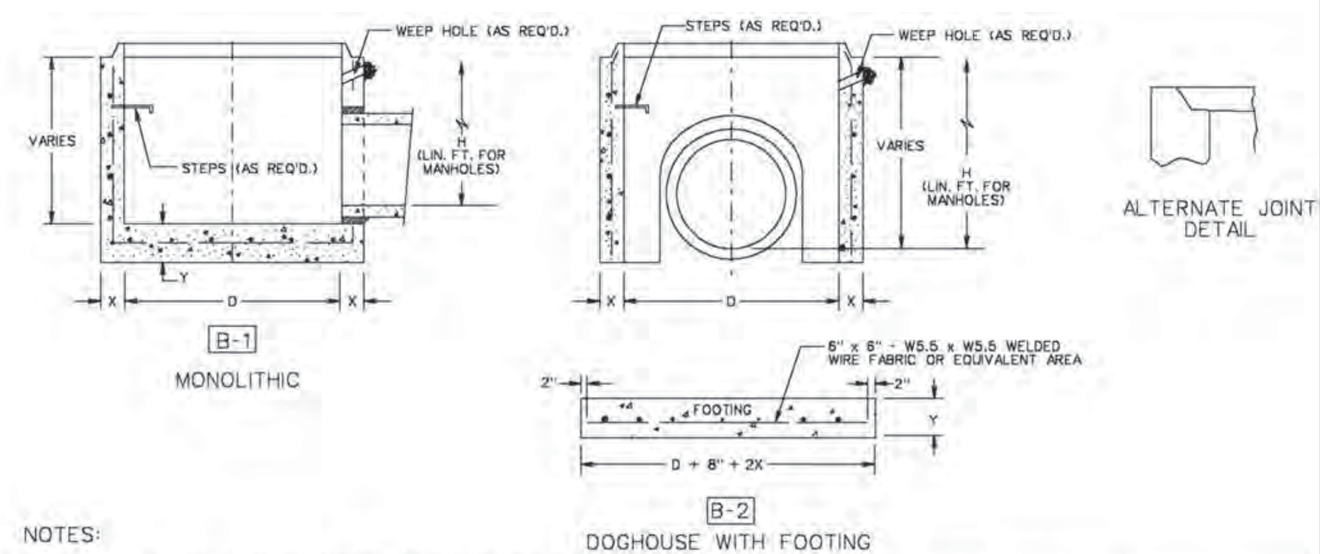
Manholes

Manholes are a required appurtenance to any sewer system. They provide access to the sewer for inspection and maintenance. Manholes should be placed at every change in grade or horizontal alignment, at every change in sewer size, at every sewer intersection, and at least every 400 ft. For larger sewers, which are readily accessible to workers, they may be spaced at greater intervals.

Only precast reinforced concrete manholes should be used except where special field conditions make it necessary to field construct the manhole with brick or cast-in-place concrete. Figure 24.14 shows two typical types of manholes. The standard manhole includes a base that is generally cast as a part of the first barrel section. The base shown is an extended base, which spreads the manhole weight over a larger area. Additional barrel sections are used as required to bring the manhole to where the eccentric cone is added. A manhole frame and cover are placed at the surface. The manhole supplier should adjust the height of the sections to comply with installation requirements. The precast supplier tailors each manhole for the specific site. Rubber boots are available that can be cast into the manhole at the locations where the sewers will pass through the manhole wall. A stainless steel clamp is used to secure the sewer to the boot making a watertight connection. The inside of the connection is grouted along with the placement of the bench (only shrink-proof grout is used). Corrosion-resistant steps are placed inside the manhole on a 12-in or 16-in vertical spacing. The exterior of the manhole is waterproofed using bituminous mastic on the surface and in the joints.

Figure 24.15 shows two types of drop manholes. A drop manhole is used to reduce slopes of incoming sewers or to permit connecting a sewer entering the manhole at a higher elevation than the main sewer. Generally, if the difference in elevation is less than 5 ft and ground water or obstacles are not a problem, the slope of the higher sewer is increased to lower the sewer to where the drop manhole will not be needed.

Doghouse manholes are typically used when a new gravity sewer will intersect an existing gravity sewer, and an existing manhole is not present. The doghouse manhole is located at the intersection of the two lines and includes the construction of the manhole base in the field through forms and cast-in-place concrete around the existing gravity sewer line (see Figure 24.16). Additional barrel sections and a cone section are added to the constructed base section until



NOTES:

1. SEE GENERAL NOTES FOR ADDITIONAL INFORMATION ON WEEP HOLES, STEP REQUIREMENTS, "H" (LIN. FT. FOR MANHOLES) DIMENSIONS, ETC.
2. ALL BASE UNITS ARE TO BE IN ACCORDANCE WITH THE REQUIREMENTS OF AASHTO M199.
3. CONCRETE SHALL BE 4000 PSI.
4. WHERE OPENINGS ARE REQUIRED FOR PIPE, THEY SHALL BE FORMED, DRILLED, OR NEATLY CUT AS APPROVED BY THE ENGINEER. THE CONTRACTOR SHALL FURNISH THE FABRICATOR WITH THE ANGLES BETWEEN CENTER LINES, THE INVERT ELEVATIONS, AND THE SIZE OF ALL PIPES TO ENTER THE MANHOLE. HOLES ARE TO BE A MINIMUM OF 4" TO A MAXIMUM OF 8" LARGER THAN THE OUTSIDE DIAMETER OF THE PROPOSED PIPE.
5. DIMENSIONS SHOWN ARE MINIMUM. ACTUAL DIMENSIONS MAY VARY WITH MANUFACTURER.
6. "D" IS NOMINAL DIAMETER.
7. IN THE EVENT THE INVERT OF THE OUTFALL PIPE IS HIGHER THAN THE BOTTOM OF THE STRUCTURE, THE INVERT OF THE STRUCTURE SHALL BE SHAPED WITH CEMENT MORTAR TO PREVENT STANDING OR PONDING OF WATER IN THE STRUCTURE.
8. TONGUE AND GROOVE JOINT ARE TO BE OF FABRICATOR'S DESIGN MEETING VDOT APPROVAL. JOINTS ARE TO BE SEALED WITH MORTAR, O-RING GASKETS, OR BUTYL RUBBER.

DIMENSIONS				
D	X MINIMUM	Y MINIMUM	SUGGESTED MAX. PIPE SIZE	ABSOLUTE MAXIMUM ☆
* 36"	4"	6"	18"	21"
48"	5"	6"	24"	27"
60"	5"	8"	36"	42"
72"	6"	8"	48"	54"
84"	7"	8"	60"	66"
96"	8"	8"	66"	72"

* DEPTH "H" OF 36" DIAMETER BASE UNIT RESTRICTED TO 4'-0" MAXIMUM.

☆ ONE THROUGH PIPE ONLY. (ONE PIPE ENTERING AND ONE PIPE EXITING STRUCTURE)

FIGURE 24.16 Typical doghouse manhole base.

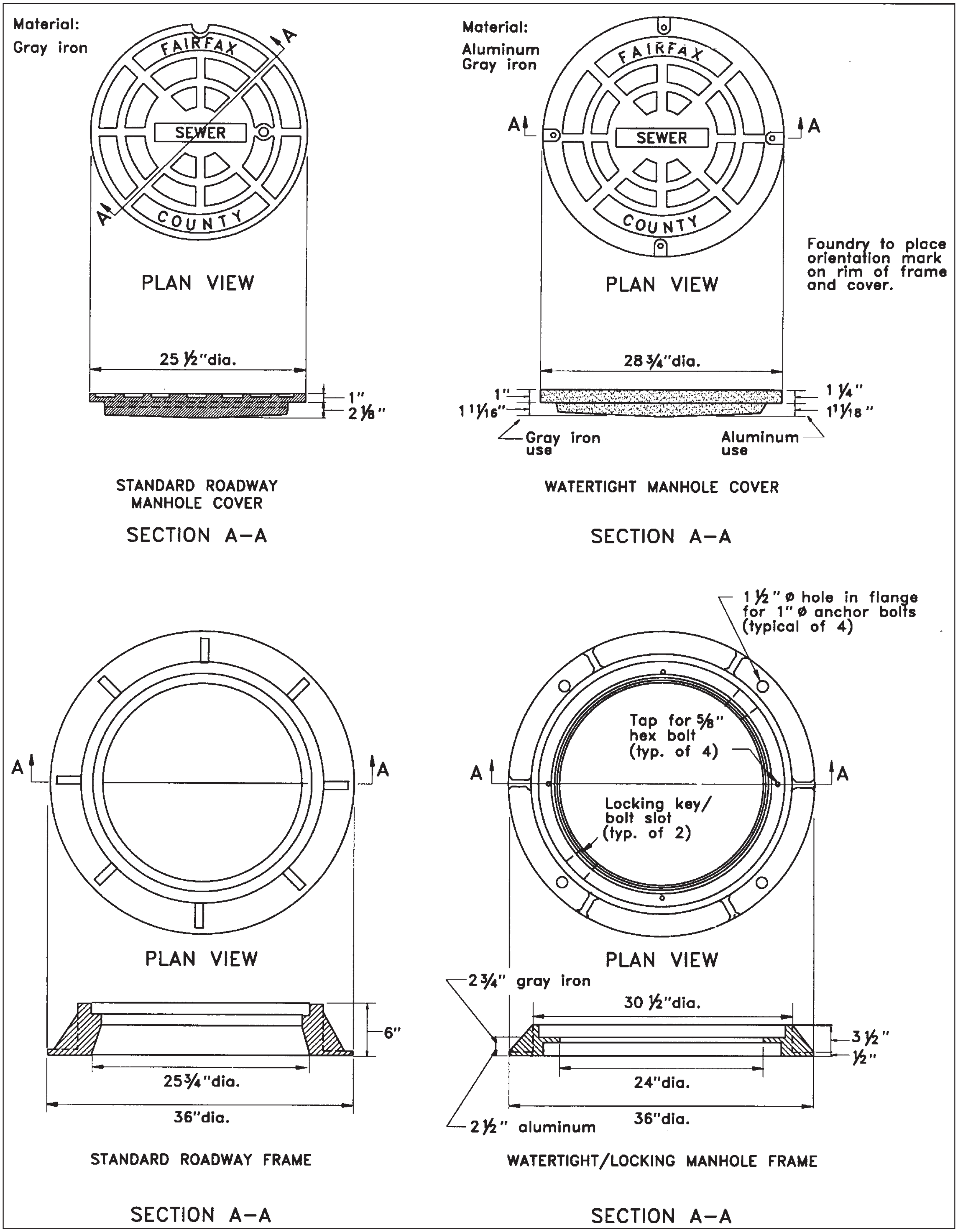


FIGURE 24.17 Typical manhole frames and covers. (*Fairfax County Public Facilities Manual*, 1993)

ground elevation is reached. Once the manhole is constructed, the top is cut out of the existing gravity sewer pipe to allow the sewage from the new line to enter the pipe, joining the collection and conveyance system.

An epoxy coating or interior liner may also be used with manhole construction if, in the opinion of the engineer, highly corrosive situations may be present that would lead to the early deterioration of the concrete manhole. Typically, these conditions could exist at manholes that receive sewage discharge from a sanitary forcemain. There is a wide variety of coatings and linings, which include epoxies applied as paint and precast high-density polyethylene linings that are formed with the original construction of the concrete barrel sections. These products can also be used in the rehabilitation of existing manholes that have not reached their useful life expectancy or are cost prohibitive to replace.

The bench is constructed to provide a smooth section through the manhole so as to reduce energy losses, to prevent the accumulation of solids in the manhole, and to provide a place for the maintenance person to stand when working in the sewer. The bench should extend to at least the springline (see Figure 24.10) of the sewer. For sewers larger than 10 inches in diameter, the bench should extend to two-thirds of the sewer diameter. The specifications should require that the base section be supplied with an extended base, that a boot be cast in the section for all sewer connections, and that the channels and bench be cast as a part of the section. All sewers entering a manhole should be provided a smooth channel into the main channel. When there is a change in sewer diameter at a manhole, the 0.8-ft depths of the sewers should be placed at the same elevation. This prevents any upstream surcharging at full flow. The change in flow direction at a manhole should not exceed 90 degrees. Where a greater change in direction is required, use two manholes with a segment of sewer between them.

In the past it has been common practice to allow for a 0.1-ft drop in sewer invert through a manhole where there is no change in pipe diameter. This is no longer necessary; in fact, the change in slope and, hence, velocity is more likely to cause problems. A well-constructed channel will not require this drop. Many manhole suppliers now provide the base section with the channel and bench cast in place when the manhole is formed. The channel invert must be smooth and have the same shape as the sewer. In all instances, the

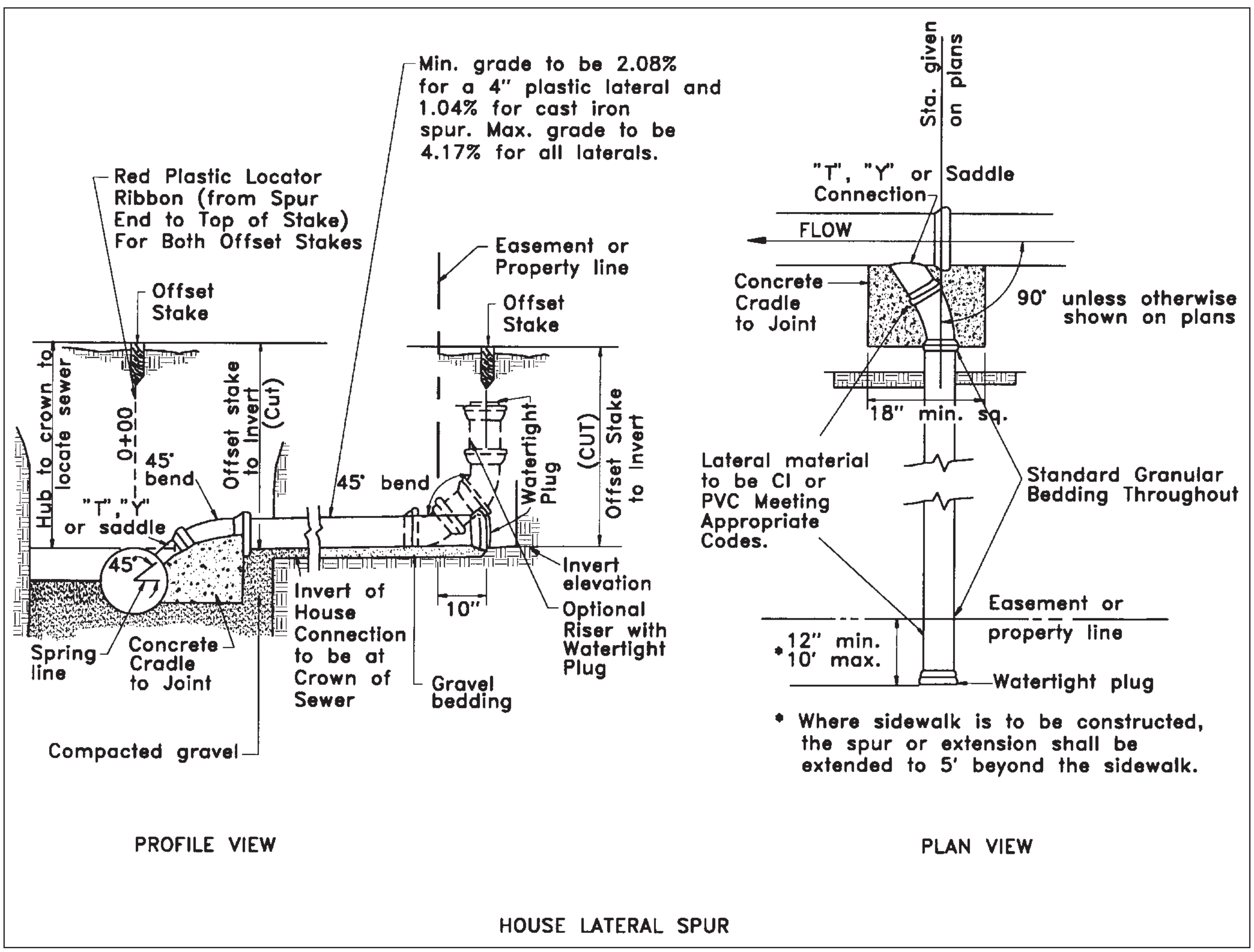


FIGURE 24.18 Service connections showing building spurs or laterals.

penetrations (openings in manhole wall for sewers) should be cast in the manhole or core drilled where an additional penetration is needed. A penetration made with a jackhammer should never be permitted. A short section of sewer is used at the manhole to provide a joint in the sewer not more than 3 ft from the manhole. This allows some flexibility for any difference in settlement between the manhole and the sewer. An air or water test is used to check the manhole for watertightness, and this requirement should also be included in the specifications.

The manhole frame and cover should be of gray cast iron. A typical frame and cover are shown in Figure 24.17. A standard frame and cover as well as a watertight/locking frame and cover are also shown in the figure. The engineer's library should include a catalog on standard manhole castings. The weight of the frame and cover must be selected to carry the expected loading. For example, a traffic-bearing frame and cover are required when the manhole is located in a street, whereas a lighter one is suitable for off-street locations. Locking frame and covers are available for use where required. Waterproof frames and covers should be used at locations where the area is subject to flooding. Ventilation to the sewer is provided through the manhole cover. When waterproof frames and covers are used, alternate ventilation should be provided for at least every 1000 feet of sewer.

Many utilities have a specific design on the manhole covers such as the name of the utility. These utilities stock the covers and sell them to the contractor.

Building Spurs

When manholes are placed in the street, the building spur (often referred to as building lateral) should be installed from the sanitary sewer to a minimum of 1 ft inside the property line. A separate spur should be connected for each lot or building site. Where sidewalks are to be constructed, the building spur should be constructed to 5 ft beyond the back of the sidewalk. It is important that each building spur be shown on the sewer plan with the station of the connection being confirmed as a part of the as-built drawings. SDR-35 or heavier pipe should be used for building spurs. The spur should enter the main sewer through a manufactured wye or tee. An approved saddle may be used when connecting to existing sewers. Some localities require that the connecting wye or ell be of ductile iron because mechanical rodding equipment will bore through a PVC connection if care is not used. Building spurs should be laid to a grade of at least 0.5 percent slope, with a minimum slope of 1 percent being provided where possible.

A wye may be installed and the extended line capped at the surface at the lot line for access in the future as needed. Where the main sewer is excessively deep, the spur should be brought to a reasonable depth prior to reaching the lot line, but the spur must be kept deep enough to serve the building. Figure 24.18 shows typical connections for building spurs (Service Connections).

DESIGN EXAMPLE

Preliminary Investigation

This design example has been structured to include principal considerations the engineer may encounter with a sewer design project. A hypothetical example, such as presented here, is considered more appropriate for this purpose than an actual design because a hypothetical case can be structured to incorporate the circumstances needed to cover many aspects of sewer design. The example assumes that a Mr. John Jenn, the owner of 40 acres of land fronting on West End Road (see Figure 24.19) has commissioned an engineering firm to design the infrastructure and obtain the required approvals so that construction permits for a single-family development on the entire tract can be obtained. This example covers the course of action the engineer may take to complete the sewer design and obtain the required approvals. Note that the engineering firm is responsible for providing the owner with complete plans and specifications that have been approved by all reviewing agencies, both local and state. When this has been properly accomplished, the contractor should not have any problems in obtaining a permit for the construction.

The first stage of the project is to conduct a preliminary investigation and prepare a report on the findings. The preliminary investigation should include:

1. Securing topographic mapping of the drainage shed that includes the 40-acre tract
2. Preparing a drawing showing the location of the 40-acre tract, the drainage shed, and environs
3. Meeting with the staff of the sewer utility (Department of Public Works or a separate authority) to advise them of the project and to obtain information on the availability of public sewer to serve the area

This early meeting with the staff of the sewer utility is also necessary to obtain information on how the utility plans to sewer the area, as shown by the Master Utility Plan for the area where the 40-acre tract is located. Several additional pieces of information are obtained from this meeting:

- The parcel of land is in an area approved to receive public sewer and that the nearest public sewer is approximately 16,000 feet to the west.
- Capacity is available in a trunk sewer located to the west, but it may be 5 to 10 years before service will be available to the property under the utility's sewer extension program.
- The utility does permit property owners to extend sewer service into areas approved for service at the property owner's expense.
- Any design for sewering the parcel will have to consider the needs of the entire sewer shed, and the comprehensive sewer plan provides for the construc-

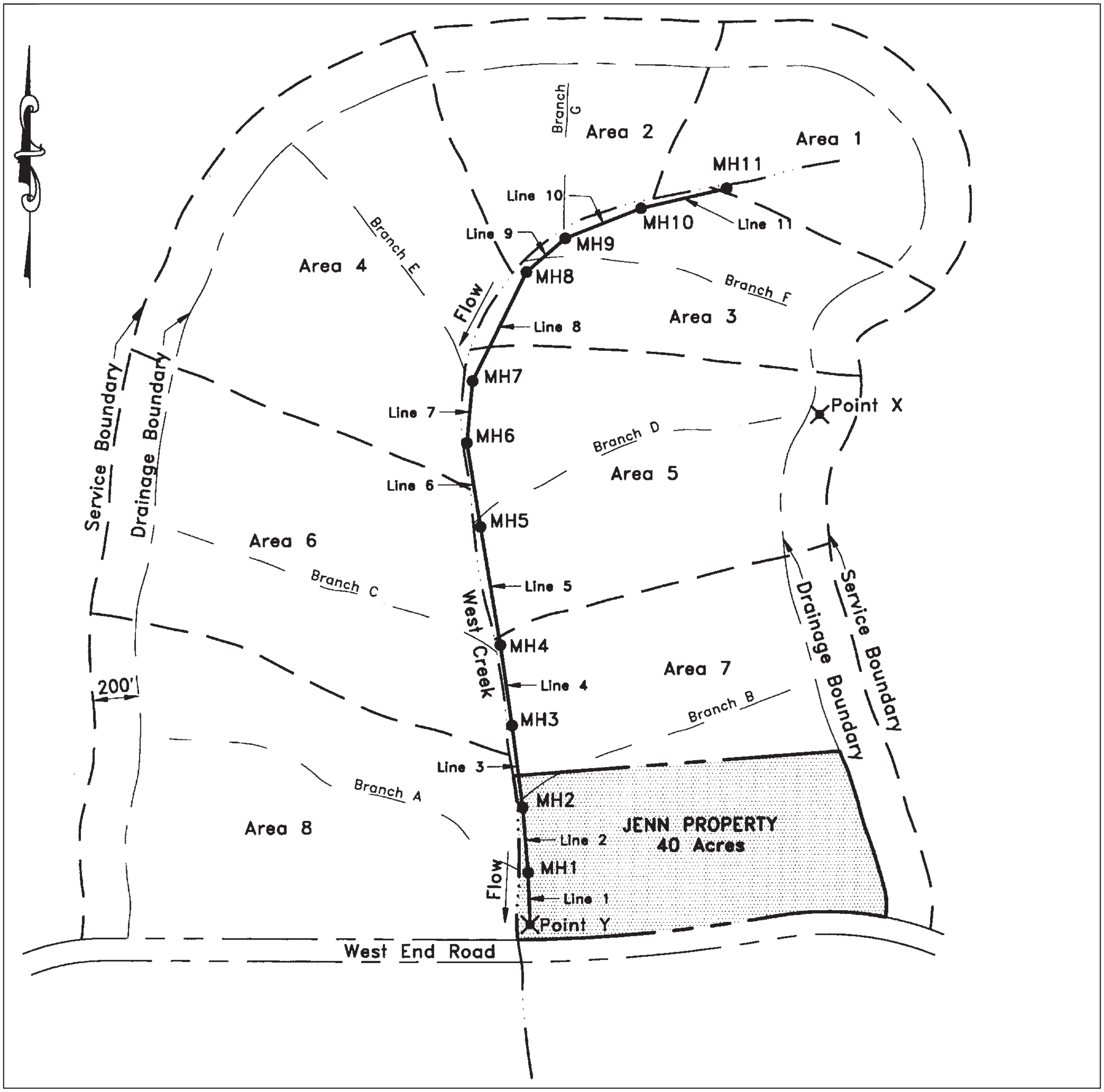


FIGURE 24.19 Sewer Shed West End Road service area.

tion of a pumping station on the adjacent sewer shed to the east that will pump the flow across the drainage area containing the 40-acre tract.

- This additional 28-acre parcel is zoned single family at four units per acre.
- The engineer was advised that the property south of West End Road is not planned for public sewer.
- A pumping station is to be located at Point Y (Figure 24.19) and a forcemain routed along the north side of West End Road to the existing trunk sewer.

The utility has a reimbursement policy whereby if Jenn, the owner of the 40-acre tract, constructs facilities that will serve off-site property, the utility will collect prorated funds from other landowners as their property is approved for sewer and pass these funds along to Jenn as they are collected. Jenn will only be entitled to reimbursement for any oversizing of utilities as required to provide service for off-site property. Note that this is only one procedure for managing a reimbursement policy, since the local policy may

TABLE 24.11 Acreage for Each Subarea as Shown in Figure 25.18

Area	Acres*	Additional Acres†	Total Acres
1	15.50	8.61	24.11
2	16.07	5.68	21.75
3	21.12	4.24	25.36
4	36.39	9.41	45.80
5	37.37	3.85	41.22
6	37.54	5.17	42.71
7	49.65	8.15	57.80
8	41.62	6.95	48.57
Totals	255.26	52.06	307.32

*Acres within the drainage boundary.
†Acres within the additional 200-ft-wide strip.

provide for reimbursement on the basis of acreage sewered or by some other procedure.

Early in the project, a meeting between the engineer and the utility staff is very beneficial to both parties and should always be scheduled.

The cost of off-site construction in this example may be more than would be economically feasible in the development of a 40-acre parcel. The principal off-site costs are those of a pumping station and 16,000 feet of forcemain. The engineer is able to apprise the owner of these costs as a part of the preliminary report. This report is completed and presented to the owner before starting design. Thus, the owner is able to make financing decisions before incurring substantial engineering costs. Project financing is not covered in this chapter, but note that the property owner has several options that should be explored. The owner himself or through his legal counsel should meet with other property owners in the sewer shed to determine whether other property owners are interested in participating in the project. The engineer may also assist the owner by sending a letter to each affected property owner advising them of a meeting to be held at the engineer's office for the purpose of determining their interest in participating in the project. The engineer would generally not be authorized to proceed with design until Jenn has made suitable financing arrangements for the construction of the project.

Establishing Sewer Service Shed

A drawing of the sewer shed is shown in Figure 24.19. The drainage boundary above West End Road is 255.26 acres. It should be recognized that, for a rural area, a 255.26-acre area may require many years for complete development, in which case something less than the entire drainage shed would be included in the planning and design associated with sewering the 40-acre tract. This is a decision that should be agreed on by the local government planners and the utility. In this example, it is assumed that the parcel is located in a major urban area where development will occur within a 10-year period once sewer service becomes available.

Contours are not shown on Figure 24.19 for clarity purposes. The figure is shown at a 1-in = 500-ft scale in order to include the entire area on a normal sheet. The engineer would normally use a 24-in by 36-in layout sheet. This would permit using a scale of 1 in = 200 ft. At this scale a 5-foot contour interval would be used, unless the terrain is extremely flat or steep.

The 255.26-acre sewer shed above West End Road has eight subsheds, each having an unnamed intermittent stream draining to West Creek. These intermittent streams are shown as Branch A through G. It is recommended that a maximum depth of 20 ft for the gravity sewer system be used for design purposes.

A 200-ft-wide strip has been used in the example to establish a sewer service boundary. This strip extends around the three sides of the drainage boundary. Lines are drawn to show the drainage limits of the eight subsheds. Also shown is the point where the off-site sewer is proposed to discharge to the West Creek shed. This is shown as Point X.

The engineer must determine how the area will be sewered. In this example, it is determined that the area will be sewered by constructing a main sewer along the east side of West Creek from Point Y to Area 1. Submains will connect at the confluence of each of the branches with West Creek. Each of the submains will sewer the respective area, with no area connecting directly to the main except through the submains. This deci-

TABLE 24.12 Planned Density

Area Number	Planned Density
1	100% single-family at 4 units/acre
2	40% townhouses at 10 units/acre
	60% new elementary school—300 students
3	100% single-family at 4 units/acre
4	100% single-family at 4 units/acre
5	100% single-family at 4 units/acre
6	100% townhouses at 10 units/acre
7	100% single-family at 4 units/acre
8	40% commercial at 2000 gpd/acre
	60% apartments at 25 units/acre

sion is made by the engineer and based on the topography. In this example, the flow for the main sewer is computed. The design of the submains and the sewer laterals would be designed as a part of the development of each parcel.

Determining Average and Peak Flow

A topographic map that shows the boundaries for each planned land use should be prepared for the sewer shed. This information is taken from the comprehensive plan for the area. The area of each use for each subshed is then determined by planimetering. The area for each subshed, as determined by planimeter, is shown in Table 24.11. The planned density for each subshed is shown in Table 24.12.

A drawing similar to Figure 24.19 would be prepared at a scale not smaller than 1 in = 200 ft with all topographic features shown including contours and land use. A map of this type is not provided in this example because of size limitations.

Table 24.13 is formatted for tabulating average and peak flow for each main sewer segment. The length of each segment is shown in column 3 of the table. The peak design flow is provided in both gpm and cfs for general information.

Table 24.14 provides information on elevations for the proposed sewer route and the associated West Creek streambed. This table would not be required in a normal design, as the information would be taken directly from the topographic map data as the design proceeds.

Note the following general guidelines:

1. Keep the sewer depth to at least 6 ft. This minimizes the impact of surface loadings.

2. Design to allow for stream crossings. The top of the sewer for all stream crossings is to be at least 1 ft below the streambed. The sewer, in the area of the stream crossing, will be concrete encased.

Line Design

The sewer design is provided in Table 24.15. Notes are provided as a part of the table to show how the data was determined. In the design example, the design is started

TABLE 24.13 Computation of Sewage Flow

(1) From Point*	(2) To Point*	(3) Length Feet	(4) Area Added†	(5) Acres Total‡	(6) Density Added‖	(7) Added[a] Ave. (gpd) Flow§	(8) Total Flow[b] (gpd)	(9) Peak Factor[c]	(10) Design Flow[d] (gpm)	(11) Design Flow (cfs)
8	7	700	1(24.11)	24.11	96 S.F.[e]	35,520	35,520	6.4	158	0.35
7	6	220	2(21.75)	45.86	87 T.H[f]	26,100	61,620	6.0	257	0.57
6	5	470	3(25.36)	71.22	101 S.F.	37,370	98,990	5.9	406	0.90
5	4	680	4(45.80)	117.02	458 T.H.	137,400	236,390	5.4	886	1.97
4	3	470[g]	5(41.22)	158.24	164 S.F.	60,680				
			X(28.0)	186.24	112 S.F.	41,440	338,510	5.1	1199	2.67
3	2	670	6(42.71)	228.95	427 T.H.	128,100	466,610	4.9	1588	3.54
2	1	290	7(57.80)	286.75	231 S.F.	85,470	552,080	4.7	1802	4.01
1	Y	250	8(48.57)	335.32	Commercial 728 Apts.	38,856 218,550	809,486	4.5	2530	5.63

*Points refer to confluence of subshed drainage with West Creek and correspond with area added as shown in column 4.
†Acres taken from mapping by planimeter (see Figure 25.18 and Table 25.11).
‡Areas are totaled to confluence of indicated streams.
‖Allowable density obtained from comprehensive plan of local government (see Table 25.12).
§Average flow per unit obtained from Table 25.2.
[a]Flow added is unit flow times the number of units.
[b]Total flow is total to indicated downstream point.
[c]Peak Factor obtained from Figure 25.2.
[d]Design flow is obtained by multiplying average flow times the peak factor to obtain gpd and then dividing by 1440 minutes/day to give flow in gpm. Cfs is obtained by dividing gpm by 449 gpm/cfs. MGD is obtained by dividing gpm by 695 gpm/mgd or cfs divided by 1.55 cfs/mgd gives the flow in mgd. Cfs or gpm can then be used with the nomograph shown on Figure 25.7 to establish head loss and pipe size.
[e]S.F. = Single-family detached housing.
[f]T.H. = Town house.
[g]Note that when the distance between points in greater than 400 ft, and intermediate number is needed. See the design tabulations shown in Table 15.5.

TABLE 24.14 Elevations Determined from Field Surveys

Station	Ground Elev. (ft)*	Stream Inv. Elev. (ft)†,‡	Station‖	Ground Elev. (ft)	Stream Elev. (ft)
0 + 00	212.0	206.8	19 + 00	221.6	217.4
1 + 00	212.0	207.8	20 + 00	222.0	218.0
2 + 00	213.2	208.2	21 + 00	222.5	218.7
3 + 00	213.7	208.9	22 + 00	223.1	219.3
4 + 00	214.4	209.3	23 + 00	223.6	219.9
5 + 00	215.0	209.7	24 + 00	224.0	220.5
6 + 00	215.9	210.1	25 + 00	224.7	221.0
7 + 00	216.4	210.4	26 + 00	225.2	221.4
8 + 00	216.6	211.0	27 + 00	225.8	222.1
9 + 00	216.8	211.6	28 + 00	226.5	222.9
10 + 00	217.2	212.3	29 + 00	227.0	223.5
11 + 00	217.4	213.0	30 + 00	227.6	224.2
12 + 00	217.9	213.3	31 + 00	228.2	224.8
13 + 00	218.5	213.7	32 + 00	228.9	225.4
14 + 00	218.9	214.3	33 + 00	229.5	226.2
15 + 00	219.6	214.9	34 + 00	230.1	227.0
16 + 00	220.1	215.5	35 + 00	230.7	227.5
17 + 00	220.7	216.2	36 + 00	231.2	228.2
18 + 00	221.0	216.8	37 + 00	231.7	228.0

*Ground elevations were taken from field topography for the selected sewer route.
†Stream elevations are for the lowest point in the stream cross section at the respective station along the sewer route.
‡The sewer route is within 25 ft of the stream at all points.
‖Station 0 + 00 is adjacent to proposed location of pumping station.

adjacent to the proposed pumping station and continued upstream. When designing sewers to serve relative flat terrain in which the ground slope along the sewer route is less than the slope required to provide minimum velocity in the sewer, the design should be started at the upper end of the system and continued downstream. This is because the sewer will continue to get deeper as the design proceeds. If the design is started at the lower end, the designer does not know what initial depth to use so that adequate cover will be provided upstream, making several trial-and-error attempts necessary.

Preparation of Construction Plans

The engineer now has all the information required to complete a set of construction drawings. It is important that the plans be clear and complete. These plans would normally be prepared on 24-in by 36-in sheets (local utility may have other requirements) and consist of:

- *A cover sheet* showing the project title, any identifying project number, a location map, and the name of the engineering firm. The cover sheet also often includes a sheet index for the drawings and the name of the owner. If the owner is a public body, the names of the elected officials such as mayor and council members may be shown as local practice requires.
- *A general notes and legend sheet.* This sheet should include specific notes for the construction of the improvements in the designated municipality or authority service area, especially if the improvements will be

TABLE 24.15 Sewer Design Tabulation*

(1) Line	(2) From	(3) To	(4) Length (ft)	(5) Peak Flow	(6) Ground Lower	(7) Elev. Upper	(8) Stream Elev. (in)	(9) Sewer Dia.	(10) Vel.	(11) Slope	(12) Head Loss	(13) Q Full	(14) Sewer Lower	(15) Invert Upper	(16) Control
1	Y	1	250	5.63	212.0	213.4	208.6	15	4.1	0.0056	1.40	5.0	204.75	206.15	Cover
2	1	2	290	4.01	213.4	215.5	209.9	15	3.9	0.0052	1.50	4.8	206.15	207.65	Stream
3	2	3	340	3.54	215.5	216.7	211.5	15	3.7	0.0047	1.60	4.6	207.65	209.25	Stream
4	3	4	330	3.54	216.7	217.9	213.4	15	3.6	0.0042	1.40	4.5	209.25	210.65	Cover
5	4	5	470	2.67	217.9	220.6	216.0	12	3.6	0.0059	2.75	2.9	210.85	213.60	Cover
6	5	6	340	1.97	220.6	222.1	218.2	12	3.1	0.0044	1.50	2.5	213.60	215.10	Cover
7	6	7	340	1.97	221.1	223.9	220.3	12	3.4	0.0053	1.80	2.8	215.10	216.90	Cover
8	7	8	470	0.90	223.9	226.7	223.1	8	2.6	0.0054	2.54	0	217.16	219.70	Cover
9	8	9	220	0.57	226.7	227.9	224.5	8	3.0	0.0070	1.53	1.1	219.70	221.23	Cover
10	9	10	350	0.35	227.9	230.1	227.0	8	2.8	0.0063	2.20	0.9	221.23	223.43	Cover
11	10	11	350	0.35	230.1	232.0	228.2	8	2.7	0.0054	1.90	0.93	223.43	225.33	Cover

Column 1 = Number of sewer segment—generally numbered consecutively upstream.
Column 2 = Number of manhole at downstream end of sewer segment.
Column 3 = Number of manhole at upstream end of sewer segment.
Sewer manholes are numbered consecutively upstream. Submains connecting to the main numbered from that point. For example, a submain or lateral connecting to the main sewer at manhole 5 would have manhole numbers of 5-1, 5-2, etc.
Column 4 = Length of sewer segment measured from center to center of manholes.
Column 5 = Peak flow calculated for sewer segment (see Table 25.13).
Column 6 = Ground elevation at downstream end of sewer segment.
Column 7 = Ground elevation at upstream end of sewer segment.
Note that the ground elevation is carried to the nearest 0.1 ft, whereas the sewer invert is carried to the 100th of a ft.

Column 8 = Stream elevation at upstream end of sewer segment. Must be able to cross stream with one ft of cover over top of pipe. Column 16 is added to show if stream elevation is controlling.
Column 9 = Diameter of sewer segment in inches.
Column 10 = Velocity of flow in sewer segment.
Column 11 = Slope of invert for sewer segment.
Column 12 = Feet of head loss in sewer segment.
Column 13 = Full capacity of sewer.
Column 14 = Sewer invert elevation at downstream end of segment.
Column 15 = Sewer invert elevation at upstream end of segment.
Column 16 = Condition controlling depth. This column is not shown on sewer design tabulations, but included here for instructional purposes. The design criteria employed in this example is that the sewer cover is to be at least 6 ft and that at least 1 ft below the stream invert. The invert of a sewer is the lowest elevation on the inside of the pipe. The invert elevation is maintained in sewer construction and design.

*Design procedure: For line 1 running from manhole Y to manhole 1, check ground slope for segment. Difference in elevation is found to be 1.4 ft, and slope is head loss divided by segment length = 1.4/250 = 0.0056 as shown in column 11. Manning's n is 0.013 (generally always used for design). Knowing n and S, from Figure 24.7 using a straight edge, the two points will establish a point on the pivot line. Maintaining the pivot point, rotate the straight edge to the required Q as shown in column 5. Note that the straight edge falls between 12 in and 15 in pipe diameter. The straight edge is rotated about the pivot point to the next larger pipe diameter of 15 in. At this alignment of the straight edge D, V, and Q full is established. The most economical condition is to lay the sewer on the same slope as the ground surface. In this example the grund slope is adequate to provide the minimum velocity of 2.0 fps. A 6-ft cover requires that the sewer invert be 6.0 ft + the 1.25-ft pipe diameter, 7.25 ft from the ground elevation at each end of the sewer segment. In some instances it is necessary to check cover at low point between manholes and the designer should always make this check. Columns 9, 10, and 13 data is obtained from the nomograph shown as Figure 25.7. Columns 14 and 15 are based on cover to be provided and head loss as shown by column 12. Check upper end invert for cover at stream crossing when submain is installed.

The rules for connecting sewer segments at manholes are: The crown of the entering and exiting pipe are at the same elevation. The 0.8th depth of the entering and exiting pipe are at the same elevation. This option has been used in this example. Note Manhole 4 where the entering sewer is 12 in and the downstream sewer is 15 in in diameter. In this case the drop in invert elevation across the manhole is 0.20 ft. If the crowns had been placed at the same elevation the drop would have been the difference in the diameter of the two sewers or 0.25 ft. Past practice has been to provide a 0.10-ft drop across the manhole where there is no change in pipe diameter. This practice is no longer considered to be necessary. If a smooth chsnnrl having the same diameter as the sewer is constructed across the manhole when the bench is made, there is no need for this drop. In fact, the change in velocity resulting from a 0.10-ft drop is likely to cause problems. Note in the data in Table 25.15 that no loss is shown across the manhole where there is no change in pipe diameter.

In cases where the sewer is at a depth greater than what is needed to provide minimum cover, the sewer slope to be used is generally the slope required to provide the minimum velocity, which is usually 2.0 or 2.25 fps. This permits minimizing the depth of construction. Never use a greater pipe size than what is required to carry the flow. Designers sometimes do this when designing sewers for flat terrain to reduce the slope required to provide the minimum velocity (Note in Eq. (25.7) that the larger the pipe diameter, the smaller the slope required to maintain a velocity). This practice will lead to maintenance problems because the actual velocity of the partially filled pipe will result in the deposition of solids.

dedicated to the municipality or authority after construction. The legend provides definitions for symbols and details used on the plan and profile sheets.

- *A general layout sheet* showing streets, lots, and sewer location. The layout sheet should be to a scale where the entire project can be shown on a single sheet. The design sheets should be overlaid on the layout sheet as an index.

- *Plan and profile sheets.* These sheets normally show the design in plan view on the top half and in profile on the lower half. All topographic data related to the design construction area should be shown. The manholes are shown and numbered. The lines are shown with bearings and distances with any angles being shown at changes in horizontal alignment. Sewer size, manhole numbering, and stationing are shown on both the plan and profile views. The plan view should show existing and proposed structures, houses, underground utilities, curbs, property lines, all storm drainage, and any other infrastructure. The profile shows the elevation of all critical points such as all manhole inverts and top of covers to 0.01 ft. Care must be taken to show the location and elevation of all subsurface utilities, foundations, and other elements important for safe, orderly, and economical construction. Field-test pits may be needed for the proper location of existing subsurface elements.

- *The plan view* is generally shown at a scale of 1 in equals 50 ft. The horizontal scale for the profile is shown at the same scale as the plan. The vertical scale for the profile is generally shown at a scale of 1 in equals 5 ft.

- *Standard details sheets.* Standard details for manhole, manhole frame and covers, special construction such as waterproof frame and covers, and stream crossings are shown on sheets as needed following the plan and profile sheets.

- *Submain and building spur connections.* In subdivisions it is common to locate the sewer near the middle of the street where possible and construct all building spurs to the property line and cap the end of the line. It is important to show the location and elevation of each spur on the drawings for later location. The spur should enter the sewer through a manufactured wye. House spurs generally do not connect to a manhole. Submains should enter the main at a manhole where the connection has been cast as a part of the manhole.

Note that the sewer design results in establishing the sewer invert profile. The sewer conduit is uniform and at steady flow conditions. The invert (lowest point inside the sewer conduit) is parallel to the hydraulic grade line (HGL). While the HGL will rise and fall with changes in flow conditions, it will always be within the pipe under gravity flow conditions. Since the HGL location varies, the invert slope is established in design and utilized in constructing the sewer.

PUMPING STATIONS

General Information

Pumping stations are common to most sewage collection systems. The collection system that does not include lift or pumping stations at one or more locations is rare. The engineer has available a wide choice of pump types giving flexibility in selecting the type of facility most suitable for a particular application.

The term *lift station* refers to a pumping facility located within a collection system to lift the flow to a higher elevation. Sewer systems located in relatively level terrain may become excessively deep, making it necessary to lift the flow up to minimum cover for the sewer. In Table 24.5, the slope of an 8-in sewer providing a velocity of 2.25 fps is 0.0042. This sewer has a head loss and, hence, a drop in the sewer invert of 4.2 ft per 1000 ft of length. If the sewer is long or if the sewer is not running with the ground slope, the depth may become so deep that a lift station is needed. The depth where a lift station becomes economical depends on subsurface conditions. The presence of a high ground water table, poor soil, or rock must be considered in making this determination. Also, the length of sewer that will be excessively deep must be considered. Utility maintenance personnel generally prefer that sewers not be over 20 ft deep if greater depths can be avoided.

A pumping station is a facility designed to lift the flow and convey it some distance, such as from one drainage area to another or from the collection system to a treatment works. A lift station is commonly referred to as a pumping station, but pumping stations are not called lift stations.

Location

A pumping station should be located so as to serve the entire sewer shed. In the sewer design example in the previous section, it was found as a part of the preliminary investigation that the limit of the sewer shed was to be West End Road. This may have been a political boundary or a decision made by the local government because of land planning. The station must be located so as to receive the sewage flow from the designated sewer shed. Some general considerations to be used in locating a pumping station are as follows:

- A lift station or pumping station should never be located in a public street.

- The station must be accessible by an all-weather service road, where the utility either owns the right-of-way or has a permanent access easement.

- The station must be located to provide protection from flood inundation. The station should as a minimum remain fully operational at the 25-year flood elevation and receive no damage at the 100-year flood level. The criteria used in determining flood protection are dictated by local policy and conditions related to the site, such as the potential for unacceptable environmental pollution when overflows or sewer backups occur. In no case should sewer backup due to pump station failure result in flooding of buildings with sewage.

- Consideration should be given to problems with noise and odor. Odor is most likely to be a consideration with flow from large long main or trunk sewers where the sewage becomes septic in the sewer before reaching the pumping station. The discharge from a forcemain is also usually septic. Equipment is available for removing odors from exhaust air. Screenings are another source of odors, and they should not be stored at locations where odors will impact the surrounding area. Accumulation of solids in a poorly designed wet well may also cause odors.

Noise will not normally be a problem at a properly designed facility. The noise level from the operation of pumps and motors is low and should not be noticeable outside the station. There will be some minor noise from the maintenance truck and crew that checks the station on a daily basis. If the station design includes on-site emergency power, the generator will need to be exercised weekly, but residential-type mufflers are available and should be used. The exercise period is usually one-half hour and should be scheduled during the normal workday.

- A buffer area of at least 100 ft around the station should be owned by the utility. A cyclone-type fence should be installed around the station to minimize problems with vandalism and, more important, reduce the possibility of accidents involving children.

- The exterior architecture of the station should not detract from the appearance of the neighborhood. A pumping station can be located in any residential neighborhood if it is designed and sited in an attractive manner. Windows should be avoided to reduce vandalism. False windows can be used where needed for architectural reasons. The owner should always be consulted about the exterior appearance of the station. The grounds should be properly landscaped for appearance and drainage. Use slow-growing shrubbery, gravel areas, and pavement to reduce maintenance requirements.

Design Types

The engineer should be familiar with the requirements of the utility that will own and operate the station. Utility personnel prefer to have equipment that they are familiar with for ease in maintenance. If the utility staff does not like the type of equipment provided, it probably will not be a successful project. It is also important that the equipment be procured through a manufacturer's representative who will be available and responsive if problems occur with the equipment.

A small lift station may serve such uses as a few houses, a business, a church, or a school. This type of station can be as simple as placing one or two small pumps in a manhole. It is widely used with submersible pumps, with the manhole housing the pumps serving as the wet well. Small grinder pumps are often used, in which case the forcemain may be a 1¼-inch plastic pipe. Pneumatic ejectors may also be used for small lift stations, but ejectors are generally located inside buildings to lift the flow from floors lower than the public sewer up into the sewer. Ejectors located inside buildings are part of the building plumbing. In most instances these small lift stations should include two pumps with automatic alternation for station reliability. Figure 24.20 shows a typical design of this type.

Moving up in capacity, the second type of pumping or lift station may be of the same general type as described earlier, except for the size or capacity of the equipment and the reliability of the station. A station of this size would always pump into a forcemain 4 inches in diameter or greater. The station should always have two pumps and generally have on-site emergency power. The engineer has many options available for selecting the type of pumping facility to be used. However, the submersible station design normally offers the most economical and functional choice for use in systems serving small communities.

Figure 24.20 shows a design employing two submersible pumps placed in a properly sized concrete manhole. The bottom of the manhole is filleted and sloped to direct the flow to the pump intake and to prevent solids from accumulating in the manhole. The pump mounting design provides for the pump to be removed and replaced by a lifting chain without the need to enter the manhole. A lifting hoist is provided as part of the station design. All valves and controls are located in a separate vault for ease in maintenance, thus eliminating the need to enter the wet well. This type of pumping station can be used for designs of any size. Where the average daily flow is greater than 0.5 mgd, the two pumps may be placed in separate chambers that are interconnected with isolation valves so that either chamber may be dewatered for maintenance.

There are several manufacturers of reliable submersible pumps. No alternative offers the simplicity, reliability, and economy that are achieved with a submersible pump station. Four-ft-diameter manholes are normally used as the wet well in collection systems; however, manholes are generally available in diameters up to 10 ft. When a large-diameter manhole is needed for locations where they are not available, reinforced concrete pipe can be placed vertically on a concrete pad. When concrete pipe is used, the design must connect the pad and pipe in a manner that prevents leakage at the joint.

While the submersible pumping station is recommended, there are hosts of package pump station designs available. Generally, the entire pumping station is shipped to the site already assembled and is placed on a concrete pad, connected to a wet well discharge, forcemain piping, and an electrical supply. Typically, this type of station is referred to as a suction-lift pumping station. The name defines how it operates: a suction pipe is placed within a wet well of simi-

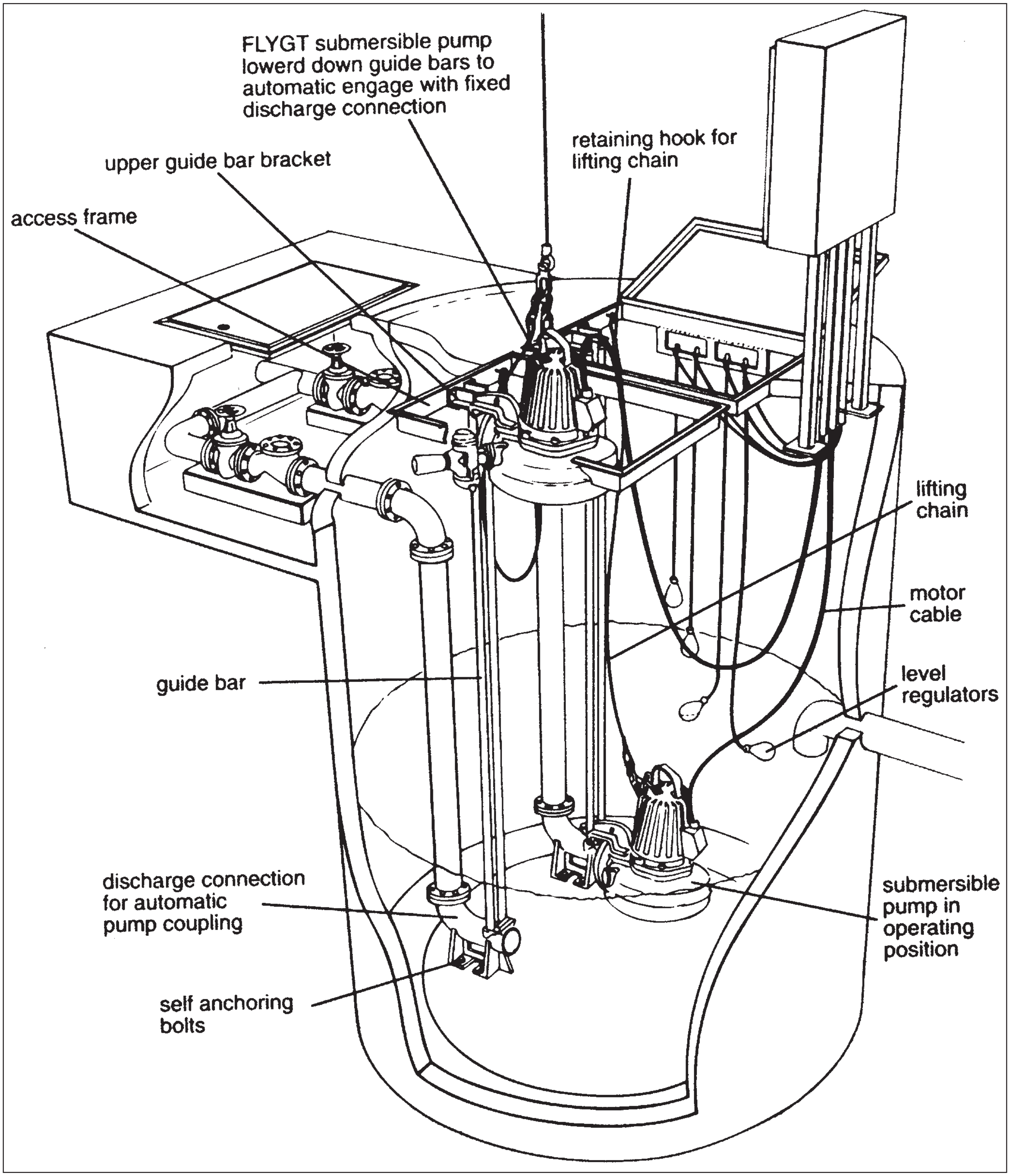


FIGURE 24.20 Typical submersible pump station. (Reprinted with permission from ITT FLYGT Corporation, 1993, Wastewater Pumps Catalog, Trumbull, CN)

lar shape and size as a submersible station, and the lines are connected to pumps placed aboveground. These pumps discharge into a forcemain that conveys the sewage to the receiving manhole in another collection system or the treatment works. The pumps and associated controls are typically housed in a prefabricated fiberglass or concrete station that is easily accessed by maintenance personnel. In addition to limitations that impact the operation of submersible pumping stations, the suction-lift station has limitations with the depth of the wet well. Based on the location of the pumping station in relation to sea level, the pumps are typically unable to pull the sewage vertically through a suction line greater than 25 ft. Suction-lift stations are generally more expensive to construct, but are typically easier to maintain than a submersible pumping station.

The engineer always has the option of designing a constructed-in-place wet well–dry well design where reinforced concrete basins are constructed and the pumping equipment, piping, and associated appurtenances are assembled in place. The wet well is the receiving chamber for the incoming flow. The wet well serves as a flow surge basin and as short-term storage during periods when the pumps are not operating. The dry well is isolated from the wet well except for the pump intake pipes. The dry well houses the mechanical equipment. The electrical equipment, including the pump motors, is generally placed in the ground floor housing located over the dry well. Both the wet well and the dry well must be suitably lighted and ventilated and have proper access for maintenance personnel. This type of pumping station can be designed to incorporate all specific requirements of the operating utility, but it is the most expensive to construct and to operate and is normally not an option for a station serving a land development project.

With designs where the maintenance personnel must enter the wet or dry wells, a minimum two-person crew must be present, whereas only one person can carry out the routine maintenance at a submersible station since no belowground tasks are required. It is important to note that all pumping station designs be checked for flotation. While more engineers and utilities are using submersible pump stations as described earlier, the older accepted practice of constructing a built-in-place wet well–dry well pumping station remains the standard design for the larger installations. Submersible pumps can be used in dry well installations.

Components of a Pumping Station

The flow schematic shown in Figure 24.21 is common to all pumping stations, except the gate valve is not needed between the wet well and the pump in a submersible design because the pump is installed in the wet well.

Screening. Screenings are the larger particles of floating and suspended matter that may clog pumps and other equipment. The quantity of screening normally does not exceed 0.5 ft^3 per million gallons of flow for residential sewage. Rags are the most troublesome items in pumping stations. The quantity of screenings to be removed depends on the type of housing and other sources of incoming sewage. The screening device should be located such that all incoming flow passes through the chamber before entering the wet well. The device should only remove material that interferes with the station operation because of the difficulty of handling removed material. Disposal methods include grinding and returning the material to the flow, burial, and incineration. Burial and incineration should be off-site from the pumping station. Maintenance crews generally carry the screenings from small pumping stations back to the treatment plant for treatment and disposal. Macerators are available for locating on the incoming sewer and should be considered for use on sewers serving industrial areas producing significant fibrous wastes.

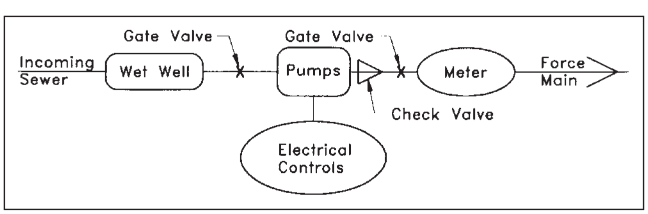


Figure 24.21 Schematic of a pumping station.

The screening device for pumping stations of small to moderate size, which primarily serve residential areas, may be a basket located such that the flow passes through the basket as it enters the wet well. Daily cleaning should be scheduled until experience shows that a less frequent schedule is adequate. The design permits overflow in case of stoppages without causing a sewer backup. The basket should be designed for easy removal of the screening. With submersible stations, the basket is lowered into place and removed by a cable hoist. The basket is held in place by guides or by hanging hooks, as shown in Figure 24.22. Hanging hooks are generally more satisfactory because guides are a maintenance problem.

Fixed bar screens are used in larger pumping stations. The bar screen is placed in a straight channel, usually located at the entrance to the wet well. The screen is inclined from 30 to 60 degrees from the horizontal. The corners of the channel should be filleted to minimize problems with accumulation of solids, particularly grit. The bars generally have a face dimension of ¼ to ⅜ inches and a depth from 2 to 2½ inches. The bar size for larger screens is determined by the structural requirements, with the face dimension limited to ⅜ inches. The clear space between the bars is normally 2 to 2½ inches. The bars are held together with a welded strip located on the downstream side at the bottom and top of the screen. A rake, having teeth size and spacing compatible with the screen, should be provided for cleaning the screen. The screenings are raked to the top of the screen, where they fall into a can having a perforated bottom for drainage or onto a drain rack. The top of the bars may be curved over to facilitate cleaning. Fiberglass racks and slide gates are available and should be considered for a design. Mechanically cleaned screens are used at large stations.

The approach velocity to the screen should not be greater than 2.5 fps at peak flow. The design must allow for the energy loss in the channel and through the screen so that the incoming sewer is not surcharged. Also, the maximum operating level in the downstream wet well must not surcharge the screen. When the screen is located in a subsurface chamber, suitable hoisting equipment should be provided for lifting the screening to the surface. A typical manually cleaned bar screen is shown in Figure 24.23. Calculations are shown for sizing a screen to handle the flow from the West Creek sewer.

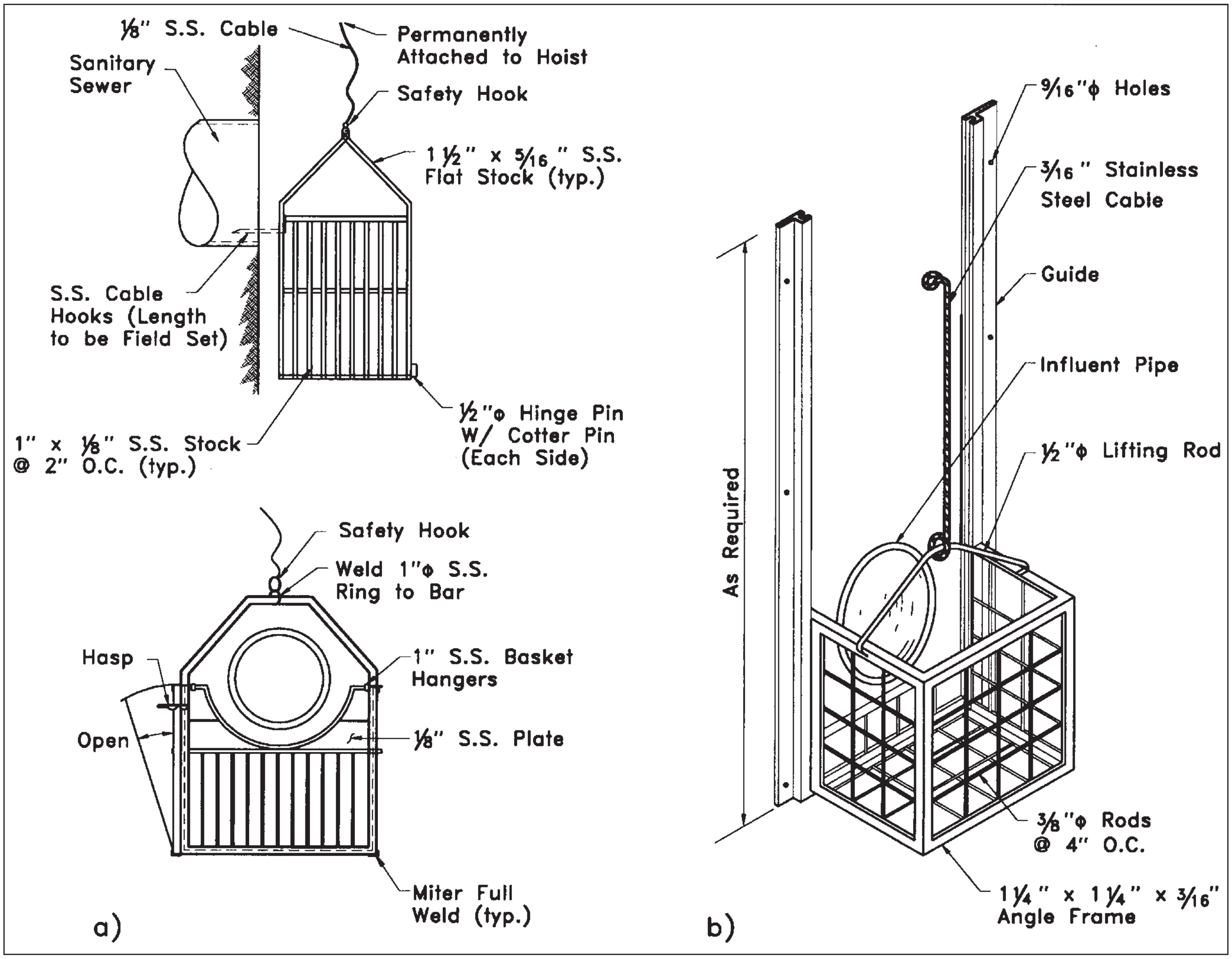


FIGURE 24.22 (*a*) Hook-mounted basket; (*b*) guide-mounted basket. (Reprinted with permission from Washington Aluminum Company Components for Water and Wastewater Plants, Catalog, Baltimore, MD)

The average and peak flows at Point Y are 1.25 cfs (809,560 gpd) and 5.63 cfs, respectively (see Table 24.13). The approach velocity is to be 2.5 fps at peak flow. The bars are to be ¼ in × 2 in with 2-in clear openings between bars.

Cross-section area of flow = Q/V = 5.63 cfs/2.5 fps = 2.25 ft^2.

Select Channel Depth. The incoming 15-in sewer at 0.8 depth of flow = 1 ft; therefore, a 1-ft depth is selected for the approach channel. Width of channel = 2.25 ft/1.0 ft = 2.25 ft = width of screen. Note in Figure 24.23 that free fall of about 3 in is provided at the influent pipe and 6 in of fall is provided through the screen chamber. The energy loss through a clean screen is small, generally less than 1 in. But most of the time the screen is partly clogged, which can materially increase the loss. Note the curved bars that aid in handling the screening. The screenings are raked onto a drain pad. After draining, the screenings are removed for disposal.

Sizing of the Wet Well. The wet well is a chamber that has been sized to receive and accumulate the incoming flow when the pumps are not operating. The wet well also provides some flow equalization, thus reducing the peak pumping rate from the peak influent flow rate. Some common design criteria for pumping stations are the following:

1. Pumps are selected to pump 2.5 times the average daily flow rate with the largest pump out-of-service. For example, if only two pumps are provided, each must have a pumping capacity of 2.5 times the average daily flow rate. If three pumps are provided that are not of equal size, the two smaller-capacity pumps must be capable of pumping 2.5 times the average daily rate. All pumping stations should have at least two pumps so that any single pump can be removed for maintenance.

2. There is a heat buildup in pump motors if the frequency of starting is too great. This can shorten the life of the motor. Most heavy-duty motors of the type used with pumps can be started up to about 10 times per hour without overheating. Starting frequency is con-

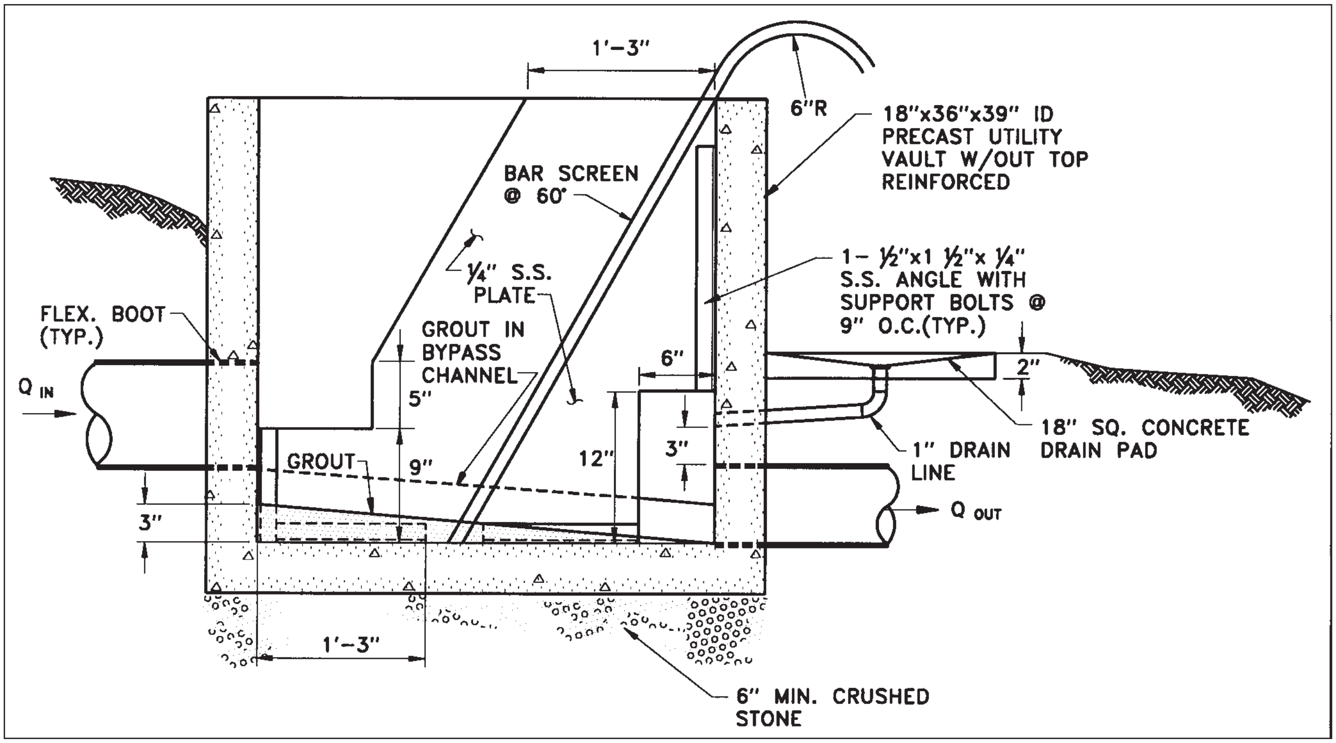


Figure 24.23 Manually cleaned bar screen.

trolled by the size of the wet well, and this should be coordinated with the electrical designer to ensure that the proper class of motor is specified.

3. The wet well should be filleted to eliminate corners where grit can accumulate.

4. The wet well should be divided into sections at larger stations so that the section supplying each pump can be isolated and dewatered for maintenance. This can be accomplished with submersible pumps by placing each pump in a separate manhole that is suitably interconnected and valved.

5. If maintenance crews are required to enter a chamber for routine maintenance, proper ventilation must be provided. The ventilation fan should be sized to provide 30 air changes per hour. Air is usually exhausted from near the floor so that fresh air is brought into the top of the chamber as the crew descends. The exhaust fan switch should be located at the top of the stairs or ladder so the fan can be started before entering the subsurface chamber.

6. A potable water hose bib should be available at each structure for use in cleaning. The potable source should be protected by installing a backflow preventer on the service line serving all outlets except the drinking fountain and bathroom.

7. A flow-measuring device should be included in the design. Ultrasonic meters are reliable and widely accepted.

8. The short intake piping and intrastation effluent piping may be designed for velocities of 6 to 8 fps, but force mains are not normally designed for velocities greater than about 5.0 fps at the peak pumping rate. Higher velocities scour and erode the pipe, and the energy loss increases exponentially with an increase in velocity. A minimum velocity of 2.0 fps should be provided at the minimum pumping rate.

9. Pump stations, except for the very small ones, should have an alarm system for the following malfunctions: power supply failure, pump fail to start, high level in wet well, failure of sump pump to operate, and failure of on-site generator to start. Other alarms may be needed at specific locations. The alarm should be relayed by telephone line or other means to a central staffed location.

10. A check valve should be placed in each pump discharge pipe to prevent backflow through the pump. A gate valve should follow the check valve so that the pump and check valve can be isolated for maintenance.

11. The top of the pump bowl on horizontal impeller shaft pumps should contain an air release valve that is vented back to the wet well.

12. No air should enter the dry well from the wet well.

13. Pumping stations located in an area where sewage backup or overflow would result in a health hazard should include an on-site power generator. These gener-

ators are normally driven by diesel engine and designed to start automatically when the off-site power supply fails and return to standby conditions when the off-site power supply returns. The units are designed to keep the facility completely operational. An on-site fuel supply for 36 to 48 hours of operation is provided as a part of the design.

Pump Selection

Sewage pumps are typically centrifugal volute nonclog impeller design. The impeller should be designed to pass a 2½-inch-diameter sphere. Other pumps, such as grinder pumps, utilize a cutting-type impeller that reduces the size of the solids that are being pumped and allows for a reduction in the discharge forcemain diameter. The pump manufacturer provides performance curves for each impeller available for the specific pump. A typical performance chart for a submersible pump is shown in Figure 24.24.

The performance curve shown in Figure 24.24 shows only the characteristics of the particular pump for a single impeller. The manufacturer casts the largest impeller that can be used with the pump. Impellers are then trimmed to the diameter required to provide the head and flow needed.

Figure 24.25 provides performance data for eight impeller diameters. The diameters, in millimeters, are shown along the ordinate of the graph. Efficiency curves are shown for the operational range of the pump, with the peak efficiency being 87 percent for the 670-mm impeller. Additional data available from catalogs includes intake and discharge connection diameter, brake horsepower, and rotational speed. Rotational speed is also an important characteristic in pump selection. Higher rotational speed increases flow and head, but bearing life is generally materially reduced. A larger pump with lower speed may cost more, but reliability is significantly improved. The pump selected should operate at less than 1700 rpm and specify any diameter between 7.0 in and 10 in. Net positive suction head (NPSH) is the difference between the absolute pressure at the suction point and the vapor pressure of the liquid. Failure to maintain the NPSH can result in vaporization of the liquid being pumped, with the resulting cavitation causing damage to the pump. The low water pump shutoff level is usually set no lower than the midpoint of the pump bowl so that pump suction is not a problem. Pump efficiency is shown to vary between 58 percent and 72 percent. Brake horsepower is shown for each of the four impeller sizes.

The total head imparted to the flow is shown as the ordinate for the indicated flow rate. The head imparted is not the same as the discharge pressure. The imparted head is the discharge energy minus the intake energy of the flow. Note that, for centrifugal pumps, the discharge head decreases as the motor horsepower requirement increases. Never oversize a centrifugal pump, as this may lead to an overloaded motor.

It is sometimes necessary to install two centrifugal pumps in series to provide the required energy input. When centrifugal pumps are installed in series, the flow through each pump is the same and the energy input is the sum imparted by the two pumps. The two pumps are designed as separate pumps and piped to operate in series. With water pumps, series impellers can be installed in a single multistage pump housing (multistage pump has two or more impellers on the same shaft within a single housing). However, this cannot be done with sewage pumps because the pump must be designed to pass solids. Therefore, sewage pumps are designed as separate pumps where series operation is required to induce the required head.

When centrifugal pumps are installed in parallel, the flows cannot be summed to obtain the flow from the two (or more) pumps. Figure 24.26 shows a pump curve that has been constructed for four pumps installed in parallel. The pump curve is constructed by selecting a head and drawing a line parallel to the abscissa. Each pump discharge for that head is added along the line. In Figure 24.26, all four pumps are identical, but the same principle applies if the pumps are different. When pumps having different performance characteristics are installed in an installation, the smaller pump will not function if the discharge head of the larger pump is greater than the shutoff head of the smaller pump. The shutoff head is the head produced by a pump at zero flow and is shown by the ordinate-intercept of the pump curve.

A system curve is then constructed by starting with the static head at the ordinate-intercept and adding the system energy loss at two or more flow rates to permit drawing the curve. The interception of the system curve with the performance for the indicated number of pumps shows the capacity for the respective number of pumps. Note that in Figure 24.26, since four pumps are identical, the distance between the curves at the total head value are the same because each pump has the same pumping capacity at any given head. However, as more pumps come online, the energy loss increases as defined by the Hazen-Williams equation and shown by the system curve. Thus, the flow capacity of two pumps is less than twice that of the single pump operating. The capacity of each pump is the same and is one-half, one-third, or one-fourth of the total, depending on the number of pumps operating.

Pumping stations serving a long forcemain should have a surge relief valve to relieve the surge from water hammer. This valve is located on the station discharge piping and is vented back to the wet well.

The incoming 15-inch sewer at Point Y has an invert elevation of 204.75 ft (see Table 24.15). The fall in the piping and bar screen is 1.00 ft, giving an invert elevation entering the wet well of 203.75 ft. Each of the two pumps are to be installed in an 8-ft diameter manhole (volume per vertical foot = 375.8 gal per manhole = 100 ft^3 for the two manholes). The minimum inflow rate is taken as about 10 percent of the average rate or 50 gpm. The peak inflow rate is 2530 gpm (see Table 24.13) and the pumping rate will be 2.5 times the average daily inflow rate (2.5 × 562.2 gpm = 1405 gpm).

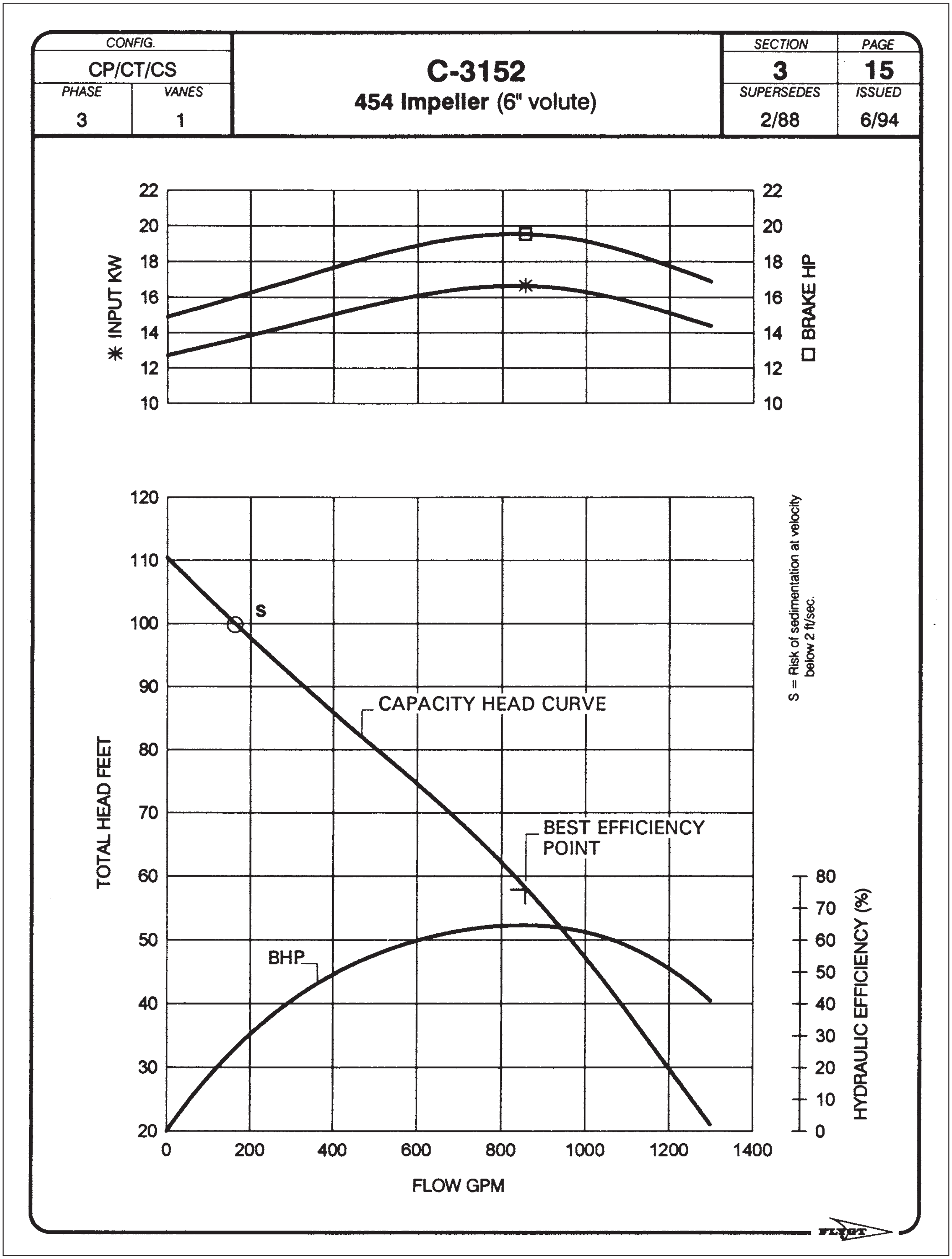


Figure 24.24 Pump performance curve. (Reprinted with permission from ITT FLYGT Corporation, 1993, Wastewater Pumps Catalog, Trumbull, CN)

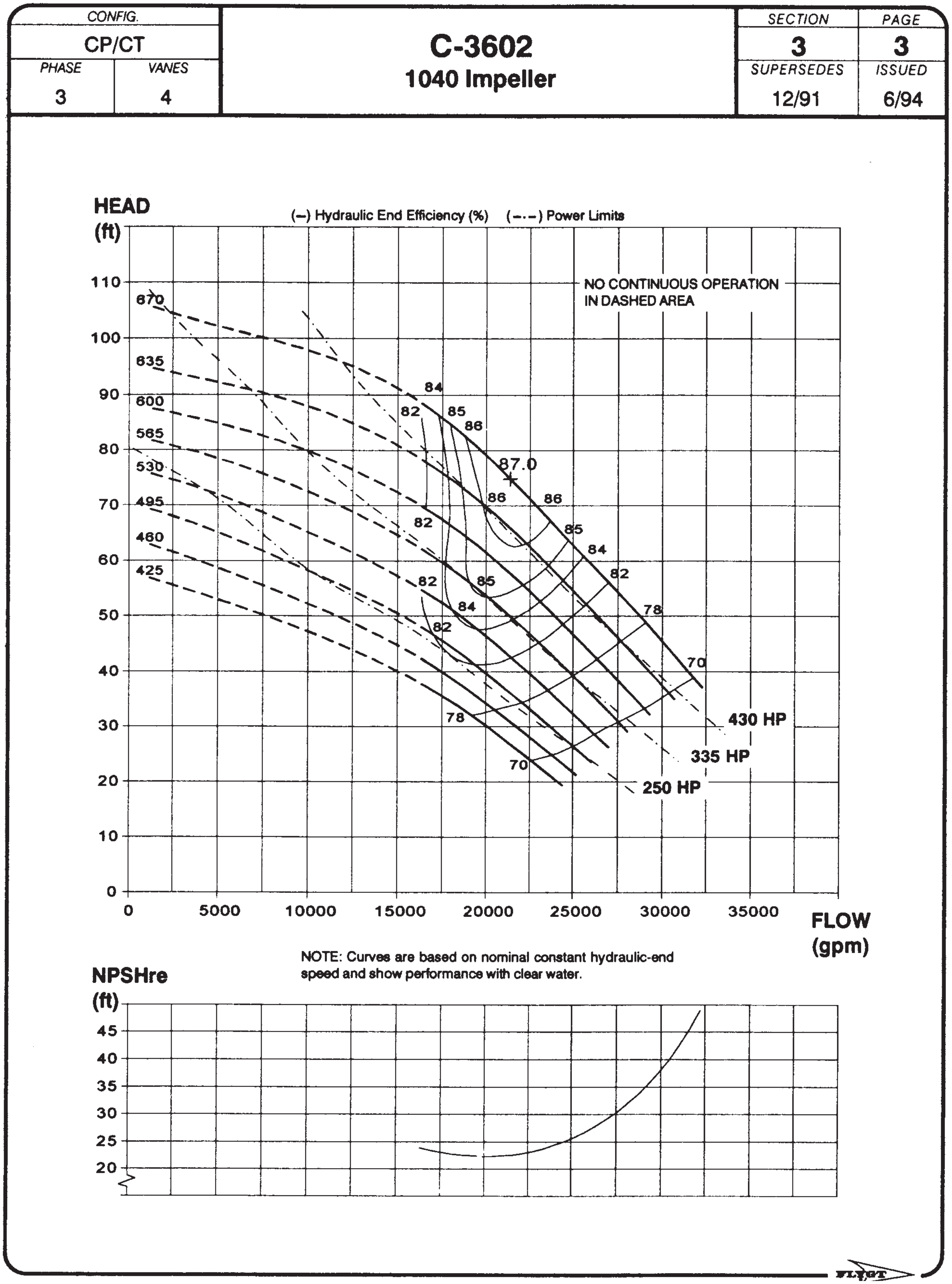


FIGURE 24.25 Centrifugal pump performance curve. (Reprinted with permission from ITT FLYGT Corporation, 1993, Wastewater Pumps Catalog, Trumbull, CN)

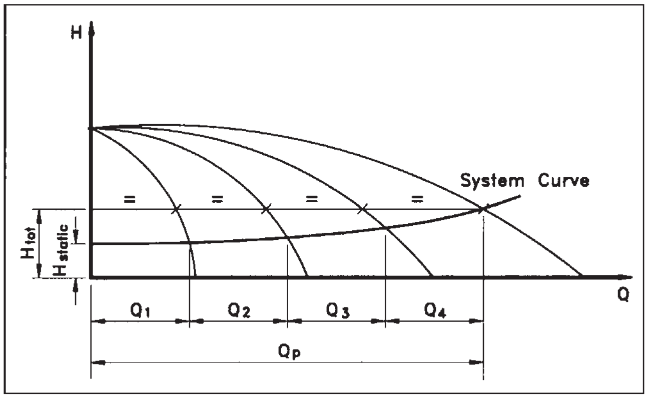


FIGURE 24.26 Performance curve for up to four identical pumps operating in parallel.

The wet well should be sized to provide at least a 4-minute run time at minimum flow. Therefore, the volume of the wet well is the pumping rate minus the inflow rate = $(4 \times 1405) - (4 \times 50) = 5420$ gal = 724.6 ft^3. The operating depth of storage in the wet well = 724.6 ft^3/100 ft^3 of volume per foot = 7.25 ft. Therefore the pump cutoff depth = 203.75 − 7.25 = 196.50 ft. These depths are shown in Figure 24.27. Note that the bottom of the manhole is the distance from the pump connection flange to the bottom of the pump mounting plate, which is lower than the pump stop level. This dimension is obtained from pump catalog information.

A suction lift exists when the hydraulic grade line drops below the center of the pump bowl. Suction lifts should be avoided with sewage pumps unless the installation is specifically designed to be self-priming. Total dynamic suction lift is the vertical distance in feet from the center line of the pump to the free liquid level in the wet well plus all energy losses in suction pipe and fittings.

The total dynamic head imparted by a pump is the difference in energy across the pump and is given by the E term in Equation 24.16:

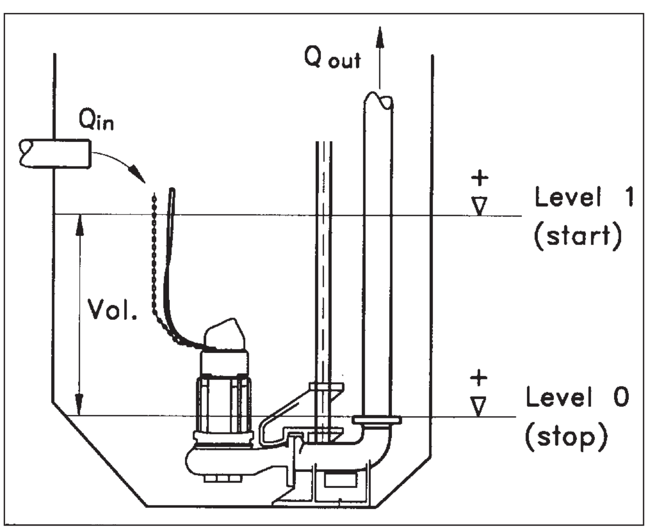


FIGURE 24.27 Schematic showing pump wet well elevations.

$$\frac{V_1^2}{2g} + P_1 + Z_1 + E_P = \frac{V_1^2}{2g} + P_2 + Z_2 + H_{1-2} \qquad (24.16)$$

Points 1 and 2 are located on the suction and discharge side of the pump, respectively. Point 1 may be the water surface level in the wet well and point 2 the free discharge point at the end of the forcemain. Points 1 and 2 must be the same for all parameters in Equation 24.16. V is the velocity, Z is the vertical distance from the same datum to the respective points, E is the energy imparted by the pump, and H is the energy loss between the two points. Each term in the equation has the dimension of feet.

Brake horsepower is the shaft input to the pump and is given by Equation 24.17:

$$\mathrm{BHP} = \frac{\text{(gpm)(Head in Feet)}}{\text{(3.960)(Pump Efficiency)}} \qquad (24.17)$$

Brake horsepower is the work done by the pump expressed in foot-pounds per minute. Raising a gallon of water 10 ft represents 8.34 lb/gal × 10 ft = 83.4 ft-lbs of work. One horsepower is doing work at a rate of 33,000 ft-lb per minute. In Equation 24.17, 3960 is obtained by dividing 33,000 by 8.34. Pump efficiency is expressed as a decimal and not in percent (obtained from pump performance curves). Velocity head is usually ignored in pump selection because it is insignificant. For example, at a velocity of 5 fps, the velocity head (see Equation 24.5) = 25/64.4 = 0.39 ft.

The profile for the forcemain, planned for construction between the West Creek pumping station located at Point Y in Figure 24.19 and the existing gravity trunk sewer, is shown in Figure 24.28. The low water level in the station wet well is 196.50 ft. The invert of the forcemain at the discharge point is 308.15 ft (obtained from field survey or taken from as-built drawings available at utility), giving a static head of 111.65 ft.

The energy loss due to pipe roughness for pressure flow is generally determined by the Hazen-Williams equation. The terms in Equation 24.18 are: V = velocity in fps, C is the Hazen-Williams coefficient, R is the hydraulic radius = $D/4$ in feet for circular pipe, and S is the hydraulic gradient =

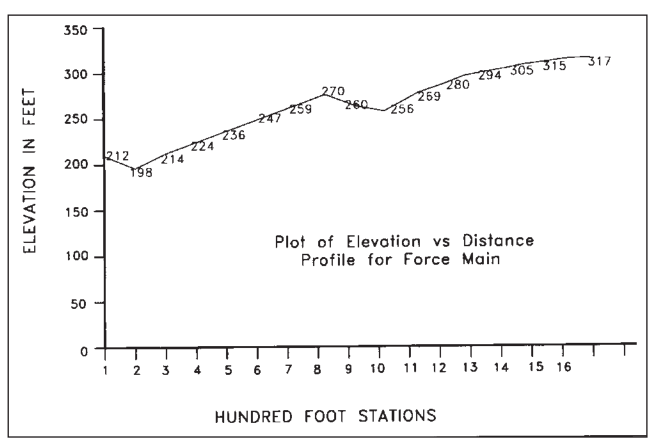


FIGURE 24.28 Profile of ground surface along forcemain.

head loss/length. Equation 24.19 is the continuity equation for noncompressible flow. Equations 24.20 and 24.21 are rearrangements of Equation 24.18. Note that the flow varies directly as *C* for a constant hydraulic gradient and pipe diameter. The technology of pipe manufacture is such that all pipe is near smooth wall. Most information supplied by pipe manufacturers indicates that a *C* value of 140 to 150 should be used in design; however, engineers generally use a value between 100 and 120. This allows for normal minor losses in the pipe and also accounts for a somewhat deteriorated pipe wall condition after the pipe has been in use for several years.

$$V = 1.318CR^{0.63}S^{0.54} \tag{24.18}$$

$$Q = AV \tag{24.19}$$

$$\frac{Q_1}{Q_2} = \frac{C_1}{C_2} \tag{24.20}$$

$$H_1 = \left[\frac{V}{1.318CR^{0.63}}\right]^{1.85} L \tag{24.21}$$

Various types of nomographs and slide rules are available for solving the Hazen-Williams equation. One type of nomograph is shown as Figure 24.29.

As determined previously, the static head for the pumping station is 111.65. The friction loss is based on 1600 ft of pipe plus the minor losses in the pumping station. The pumping rate is 1405 gpm or 3.13 cfs. Forcemains are generally designed for a velocity at peak flow of around 5 fps. From the continuity equation and Figure 24.29, it is found that a 12-in pipe at a velocity of 5.0 fps will have a capacity

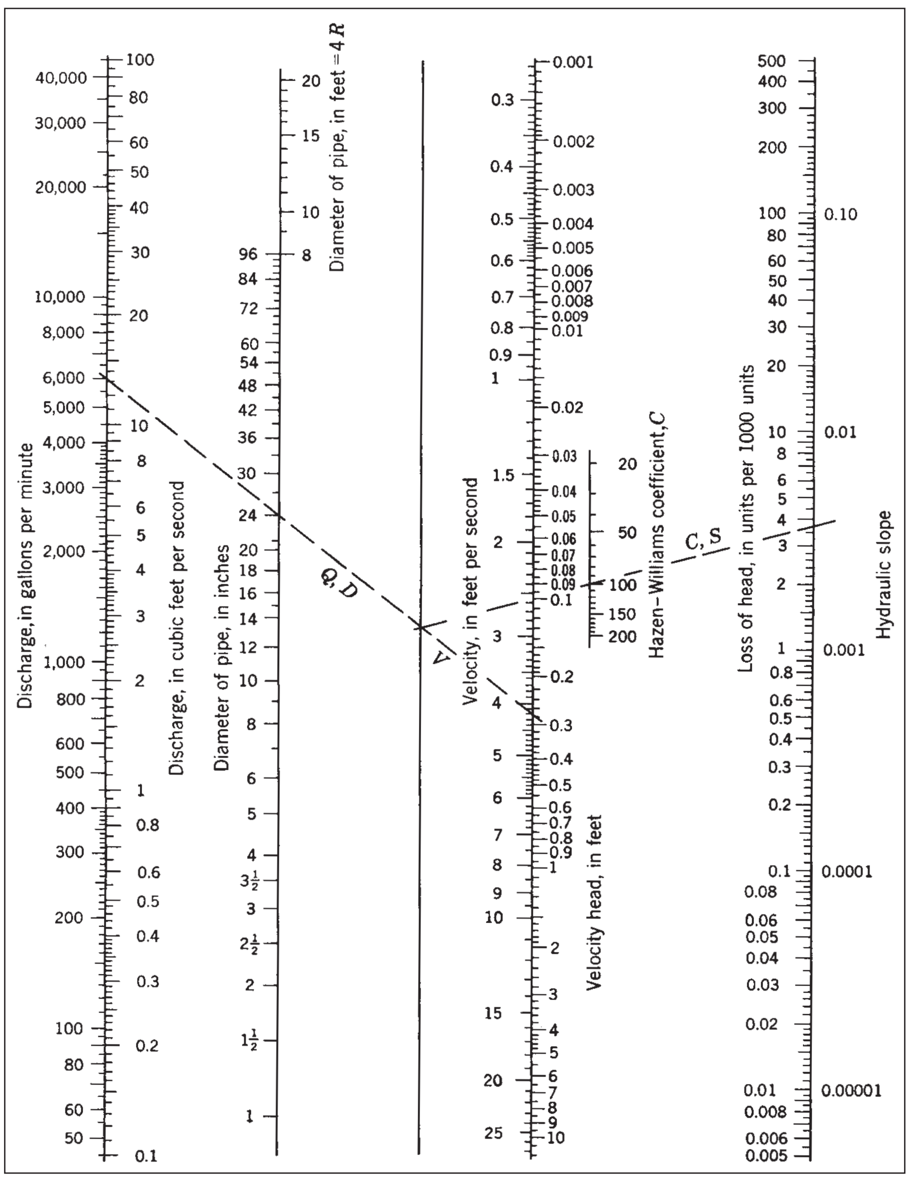


FIGURE 24.29 Alignment chart for Hazen-Williams formula for pipe flow (From *Design and Construction of Sanitary and Storm Sewers, Manual of Practice No. 9,* ASCE 1969. Reprinted with permission from the American Society of Civil Engineers, New York)

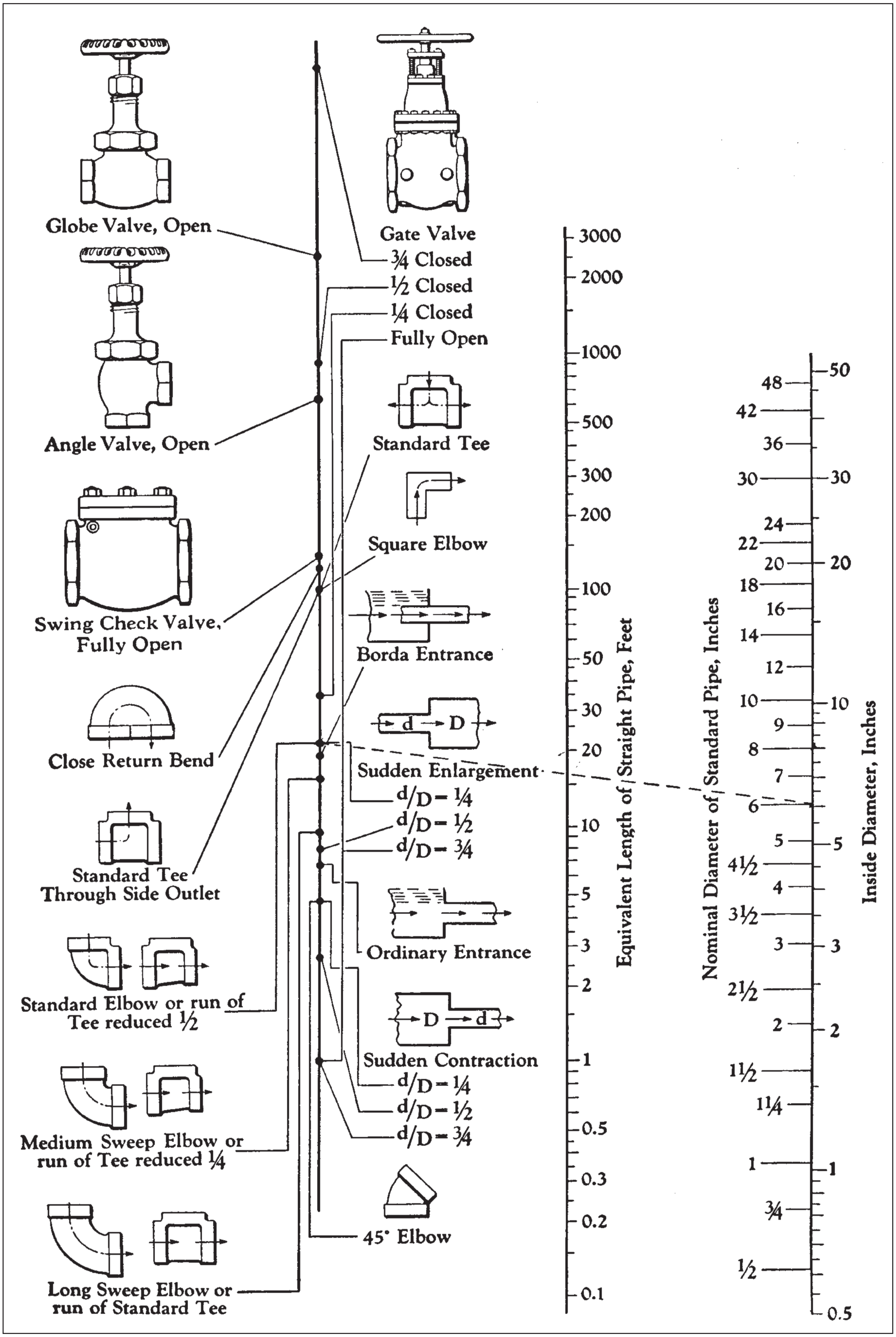


FIGURE 24.30 Equivalent lengths for minor losses. (Reprinted with permission from Crane Co., Stamford, CN)

of 1737 gpm and that a 10-in pipe requires a velocity of 5.7 fps to carry 1405 gpm. The 12-in pipe is selected for the forcemain because the friction loss will be less and because there is another area at station 10+00 that may use capacity in the forcemain at a later date.

Since the flow from the pumping station will be small for several years, it is decided to install less than the full pumping capability at this time. A forcemain should have a minimum velocity of 2 fps when the pumps are operating. Thus, the initial pumping capacity will be at least 710 gpm. Figure 24.29 shows a hydraulic gradient of 0.0016 when using a design *C* of 120 and a flow of 710 gpm in the 12-inch pipe. The hydraulic gradient at 1405 gpm is 0.0056.

Minor losses are losses in valves, bends, and segments of a conduit that produce turbulence over that for straight pipe. These losses are usually neglected in a pipeline, but they can become significant in a pumping station. One method of accounting for minor losses is by use of Figure 24.30. Knowing the source of the minor loss, the information from the figure can be used to determine an equivalent length of straight pipe. For example, a check valve is equivalent to 80 ft of 12-in pipe. The following minor losses apply to the West Creek pumping station: one check valve, one gate valve, two elbows, and one tee, giving equivalent lengths of 80 ft + 6 ft + 33 ft (2) + 70 ft and a total equivalent line length of 1600 + 222 = 1822 ft. At the hydraulic gradient of 0.0056 the initial friction head loss will be 10.2 ft, which is added to the static head and gives a pumping head of 111.65 + 10.2 = 122 ft. The pump selected, as shown by the performance curve in Figure 24.24, will deliver about 750 gpm at the required head. This pump will operate at about 53 percent efficiency and require a 40 Hp motor.

The pump selected will accept larger impellers and motors as shown by the catalog data. These can be changed when the need arises without having to replace the pump. The daily cost of pumping can be determined as follows:

BHP = (750 gpm)(122 ft)/(3960)(0.53)
= 43.6 (See Equation 24.15)
Electric Power = BHp/Efficiency of motor
= 43.6/0.92 = 47.4 Hp
Cost = (Hp) (0.746 kW/Hp) (Hours)[1] ($/kWH)
= (47.4) (0.746) (24) (0.40)[2] ($0.08)[3]
= $27.16/day

Other appurtenances to be included in a forcemain design include air relief valves and blowoff valves. Air relief valves must be placed at high points in the forcemain, as an accumulation of air will restrict the area of flow and result in a decreased carrying capacity of the line. It is seen from the line profile in Figure 24.28 that an air valve is needed at about station 8+00. An air relief valve for sewage must be used. The valve is placed in an enclosure such as a manhole. Blowoff valves are located at low points in the line to permit draining the line for maintenance. A blowoff valve is usually a gate valve or a plug valve. The profile of the main shows that a blowoff valve is needed at about station 10+00. Plug valves are generally preferred over gate valves because of the ease of operation. A plug valve only needs to be turned 90 degrees to open or close, whereas a gate valve requires much more effort and time to open or close.

Solid-state frequency controllers are a very reliable means of varying the speed of the pump motor. Variable-speed pumps should be considered for pumping stations, as their use minimizes surges in the forcemain from the constant-speed pump cycle. The variable-speed feature results in the pumping rate matching the incoming flow rate. Variable-speed pumping stations at sewage treatment plants greatly reduce surge waves through the plant.

DESIGN OF SANITARY SEWERS WITHIN SUBDIVISIONS

General Information

The previous section presents procedures for the design of a main or trunk sewer such as might be needed for sewering an entire sewer shed. This section presents the principal elements that are generally applicable to the layout and design of a sewage collection system to serve a subdivision or development.

The design of a sewage collection system for a subdivision generally requires fewer hydraulic calculations than is needed in the design of a main sewer, such as presented in Tables 24.13 and 24.15. There are many important aspects in the layout and design of any sewage collection system, and an experienced engineer should be involved in the process. A poorly conceived layout of a collection system will increase the construction costs and generally result in additional maintenance requirements. Care must also be taken to ensure that all lots can be properly sewered.

The hydraulics of sewers as presented, along with the data in Table 24.5, apply to all sewer designs. However, the calculations required in the design of collector sewers are generally much less complicated than what is required for larger sewers. As shown in Table 24.5, an 8-in sewer flowing full at a slope of 0.0042 ft/ft, and a roughness coefficient *n* of 0.013, has a capacity of 354 gpm (0.51 MGD). At this flow the peaking factor is 5.0 (see Figure 24.2), giving an average daily flow for design of 0.1 MGD (hydraulic design flow divided by peaking factor = average daily flow from source). Thus, an 8-in sewer will sewer 270 single-family houses (270 SF units times 370 gpd/unit = 99,900 gpd) or 333 town houses (see Table 24.2 for average daily flow per unit). Likewise, a 10-in sewer will serve 476 single-family units or 587 town houses

[1] Although 24 hours is used in the example, pump may operate fewer hours per day and this would be used in the equation period.

[2] Since the pumping rate is 2.5 times the average daily flow, the pump will operate only 40 percent of the time when the flow reaches the design rate. The flow and pump run time will be less until the sewer shed is developed to design density.

[3] Power costs are assumed as $0.08 per kilowatt-hour.

(peak factor = 4.5). A 12-in sewer will serve 700 single-family units (peak factor = 4.4) or 863 townhouses.

These sewer capacities are based on a minimum velocity of 2.25 fps. When a sewer is placed on a slope greater than required to provide the minimum velocity, the sewer capacity is increased in accordance with the Manning equation (see Figure 24.7). Generally, the sewer design for the normal subdivision does not require the calculations of flow and tabulation of data as shown for the larger-capacity main sewers by Tables 24.13 and 24.15. For subdivisions where the number of units is less than 500, the engineer is concerned with selecting the most appropriate sewer layout and ensuring that the sewer depth is sufficient to provide gravity drainage from the units served and that the sewer slope is equal to or greater than required to provide a velocity of 2.25 fps (slope greater than 0.0042 ft/ft). When designing the sewer collection system for single-family subdivisions greater in size than 500 units or town house developments greater than about 800, the design engineer should perform the design calculations as shown for large sewer mains. The upstream terminal segment of a sewer line should be placed on a 1 percent slope because this segment will serve only a few houses and the greater slope is needed to ensure that adequate scour is provided at the low flow. The minimum diameter for a public sewer is 8 in. Also, as noted previously, infiltration should essentially be zero in a properly constructed sewer. The unit flow data given in Table 24.2 includes an allowance for infiltration.

Feasibility Investigation

Often an engineering firm will become involved in a feasibility investigation. This investigation, generally conducted prior to the developer purchasing the property, is important in that it confirms the zoning of the parcel, the availability of an adequate water supply, and sewer service. The investigation should also discover any limitations to development, such as environmental or physical limitations.

Zoning for the parcel dictates several features of the development that impact the sewer layout. These features include street width, lot size, sidewalk and curb and gutter requirements, and building setbacks from property lines. This chapter is concerned only with items related to the sewer design. A more complete description of items associated with a feasibility investigation is included in Chapter 5.

The Preliminary Plan

An experienced engineer should direct the preliminary plan design. Many important aspects leading to the success of the development are related to the preliminary plan. Items such as the boundary shape of the parcel, topography, and the location of existing connecting roads and utility lines influence the location of streets and consequently the planimetric design of the sanitary sewer system. While it is preferable that utilities such as sewer, water, and gas be located within the public street for ease of maintenance, this may not be possible for all sewer lines because of topographic considerations. When the sewer is located within the street, it is generally located along the center line except for curvilinear street segments where the manholes are located so as to keep the sewer within the paved street area. Locating the sewer as near as feasible to the center of the street results in equal lengths of building spurs to the units on each side of the street. The sewer should never be located under the curb because access for maintenance is thereby limited. Most organized utility departments have regulations on the location of utility lines because uniformity in location and construction methods throughout the system aids in maintenance.

During preparation of the preliminary plan, the engineer's task is to select a sewer layout that will most effectively serve an area at the least cost while providing long-term reliable service with minimum maintenance. The principal items affecting construction costs are the length of sewer, sewer depth, and subsurface obstacles to construction—all of which must be investigated and confirmed as part of the preliminary design. Deep sewers are particularly expensive when construction is in rock. The principal items affecting maintenance costs include infiltration and stoppages. Both items are related to the quality of the material specified by the engineer and to the quality of the construction. A properly designed and constructed sewer should require little, if any, maintenance. Good engineering includes specifying the proper materials and construction requirements and providing competent inspection of the construction, the fine details of which are determined during development of the final plan.

Final Plan

The engineer should not proceed with the preparation of the final plans for a development until the preliminary plan review has been completed and all departments of the local government have approved the plan. In most instances, one department will act as the control department and distribute the plans to the necessary departments and all review comments will come back through the control department. While the sewage utility, whether it is the Department of Public Works or another authority, will review and comment on the sewer system proposed, the preliminary plan will be reviewed by a number of departments and agencies.

A public or common sewer is a sewer that serves two or more building units. A private ownership segment of sewer should never serve more than one customer. All segments of common or public sewers that are not constructed within public right-of-way should be within dedicated easements. A fifteen-foot-wide easement is desirable, with the sewer line located at its center. Easements should not straddle lot lines because homeowners often plant shrubbery or construct fences along property lines, making access to the sewer difficult. Easements should extend to the development boundary at locations where the sewer will need to be extended in the future to serve off-site property.

Proper separation must be maintained between water and sewer lines. Regulatory agencies generally require a minimum horizontal separation of 10 ft between the two conduits. Where field conditions preclude a 10-ft separation, some agencies will permit construction with a 5-ft horizontal plus an 18-in vertical separation with the water line higher. Special design requirements may be used where suitable separation cannot be maintained. Special conditions may include the use of ductile iron pipe for the sewers or other safeguards to ensure that the water lines do not become contaminated in case of line leakage or breakage. Sewer lines placed within 20 ft of buildings may require special construction, such as concrete encasement, to ensure that any leakage will not seep around the building foundation. Also, if a building is located near or over a sewer, it may not be possible to access the sewer for any required maintenance.

Sewer depth is established by the elevation of the buildings to be served. The sewer should be sufficiently deep to permit gravity drainage from all buildings if possible. For residential subdivisions, the sewer depth is based on the building construction. If the homes have basements, the sewer should be at sufficient depth to gravity sewer the basement. Basement floors will generally be about 6 ft below finished grade at the highest point next to the house. An additional 2 ft of depth is needed to allow for the basement foundation, as the house sewer should be located below the wall foundation and not through the foundation. The building spur (sometimes referred to as the house lateral or house sewer) should be placed on a minimum slope of ¼ in per foot or 2 ft per 100 ft (slope = 0.02 ft/ft). Plumbing codes allow a slope of 1 ft per 100 ft (slope = 0.01 ft/ft) for sewers under conditions where the greater slope cannot be conveniently provided. Thus, the invert of the house spur at the connecting point to the public sewer, where the public sewer is located in the center of a 50-ft street and the setback for the house is 50 ft, is 9.5 ft lower than the highest point of the finished grade at the house wall (from above 6 ft + 2 ft = 8 ft at outside of building foundation plus 1 ft drop in elevation in the 50-ft distance between the house and front property line plus ½-ft drop in elevation in the 25-ft distance from the property line to center of street). The invert of the public sewer is the sewer diameter plus 1 ft to allow for the wye connection, lower than that of the incoming house spur (see Figure 24.18 for typical spur connection to public sewer). Thus, a total vertical drop of about 12 ft between the highest proposed grade at the house wall and the invert of the public sewer is needed to ensure gravity drainage when the house is constructed.

In relatively level terrain, there will be a drop across the lawn of about 2 ft between the front building wall and the street thats results in a sewer about 8 ft to 10 ft lower than the street. Sewers should not be constructed deeper than 20 ft except where alternatives are not available because of the difficulty in maintenance of deep sewers. Topographic conditions may make it necessary to locate sewer lines along the back of some lots in order to provide gravity drainage at a reasonable sewer depth.

Since, as noted previously, design calculations are seldom required for sewers within a subdivision, sewer slopes are shown on the profile for each segment of sewer. The slope is constant between manholes.

The design engineer should follow certain rules in selecting sewer slope. The slope for each segment of sewer running between adjacent manholes is selected on the basis of design conditions. The overall design objective is to design the collection system that can be constructed most economically while maintaining good engineering practice. This generally means keeping the sewer as shallow as possible while complying with the following criteria:

1. Minimum sewer slope—the slope required to provide a velocity of 2.25 fps, or the slope required to carry the required flow, whichever is greatest.
2. Minimum cover
    a. Sewers located in streets should have at least 6 ft of cover. If less than 6 ft of cover is provided, special bedding may be needed because of the superimposed load from traffic.
    b. Sewers located within off-street easements should be placed below the freeze depth or at least to a depth of 3 ft.
    c. Sewer segments serving a building lateral should be at sufficient depth to provide gravity drainage from the building served.

Figure 24.31 shows a portion of a final plan. The planimetric sewer layout is highlighted on this drawing. The final grading contours are shown along with the storm drainage. The manholes have been numbered and the locations of the house laterals are shown.

Plan and Profile

A plan and profile is prepared showing all utilities including the sewers. If the sewer is located within a street, the lines are a part of the street plan and profile. All existing and proposed underground utilities should be shown on these drawings. If underground utilities are not shown, the construction contractor is likely to damage them, leading to additional costs.

A plan and profile sheet is used for presenting this design. The plan view is shown on the top half of the sheet and the profile is shown directly below on the bottom half of the sheet. The plan and profile view for the final plan of Figure 24.31 is shown in Figure 24.32. The scale of the original drawing is 1 in = 50 ft. In the profile view the horizontal scale of the profile is the same as that of the plan view. The vertical scale is 1 in = 5 ft. The larger scale is used to show the detail needed for construction. The drawing is

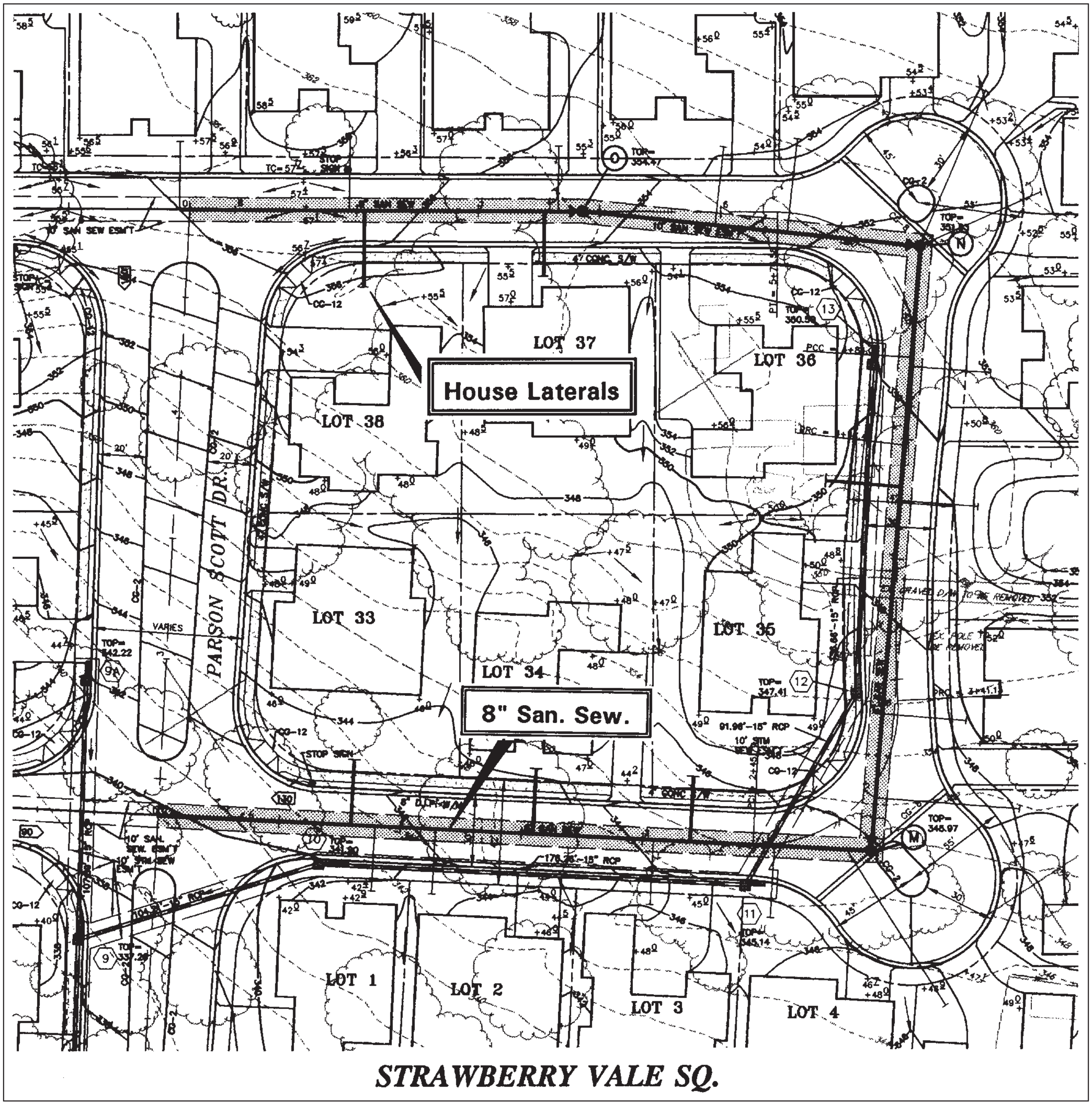


Figure 24.31 Final plan.

carefully constructed, as the contractor may need to scale some dimensions from the drawing during the project construction.

Corresponding manhole numbers are shown on both the plan and profile views. The building lateral locations are shown on the plan view, but note that the stationing and elevation of each building lateral at the lot line are also shown on the profile view. The contractor must construct the sewer as shown. Sewers located in a street are constructed to just inside the property line and marked at the surface with a stake so that the house plumber can access the sewer without disturbing the street. He keeps a set of plans in the field that are kept current with field conditions being noted as the construction progresses. This field set of plans is used to construct as-built drawings that become record drawings. The utility crews can then use these drawings for maintaining the sewers in future years.

The manhole stationing along with the sewer slopes and diameter is shown for each segment of sewer. Note that the sewer grades are considerably greater than the 0.0042 ft/ft required to provide the minimum velocity of 2.25 fps. The water line is placed to provide 4 ft of cover, whereas the sew-

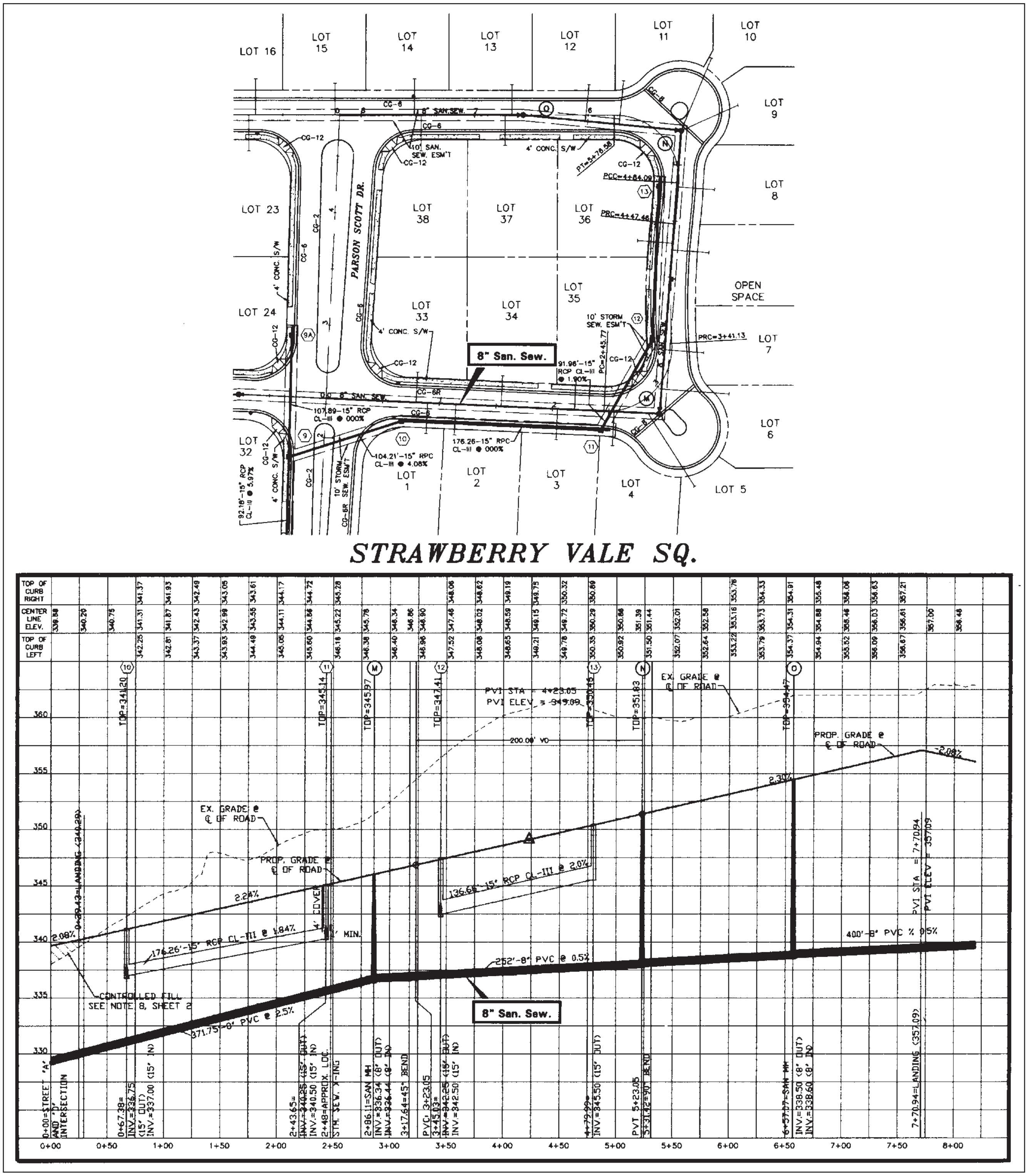


FIGURE 24.32 Example of a plan and profile view for a sanitary sewer line.

ers are required to be much deeper in order to provide gravity drainage from the buildings. All information needed by the contractor to construct the sewer, roads, and other utilities is shown on the plan and profile. The engineer must be thorough in ensuring that all underground conditions are shown on the final plan and profile. Existing underground utility location can be obtained from as-built drawings and supplemented through field surveys and test pits. Specifications are prepared to establish the allowed type of pipe material, the type of bedding required, and the acceptable infiltration. This information can also be included on the plans as notes.

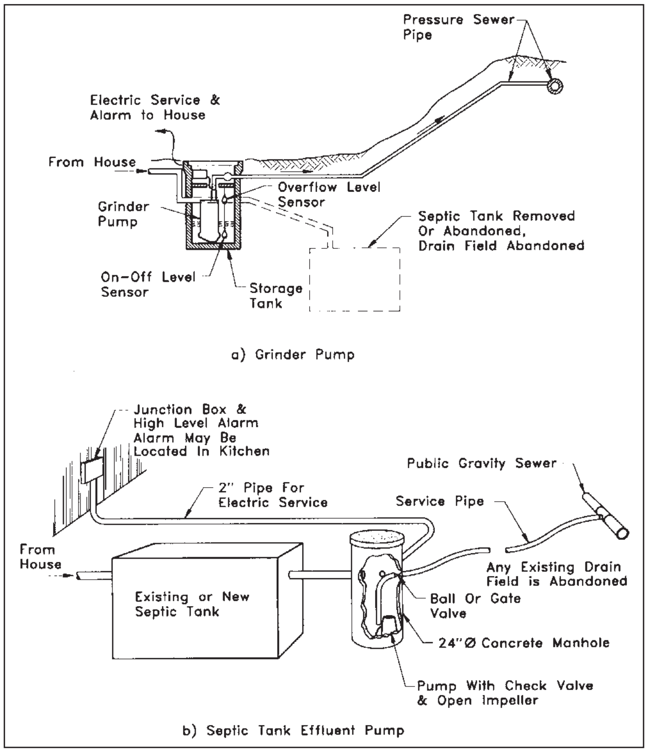


Figure 24.33 Flow diagram for pressure pumping systems.

PRESSURE SEWERS

A pressure sewer collection system is used to reduce costs relative to the cost of a conventional gravity system. The technology may be the only feasible means of sewering some areas. Pressure sewers are particularly applicable for sewering less populated areas, and developments or communities located in hilly or rocky terrain. Conventional gravity sewers may need to be deep and costly to construct in areas where the topography is undulating. Also, a high water table may make the construction of gravity sewers economically unfeasible. Pressure sewers also have merit other than lower construction cost. Reliable pumping equipment is available. The technology requires no modification to the house plumbing and, therefore, the use of pressure systems causes little inconvenience to the homeowner.

The two major types of pressure sewer systems are the grinder pump (GP) system and the septic tank effluent pressure (STEP) system. Figure 24.33 shows the basic elements of both systems. A typical grinder pump is shown in Figure 24.34. The GP system consists of a grinder pump that receives the flow from a dwelling or other activity and pumps the flow into a pressure forcemain. The GP system may also be installed to replace an existing septic tank system, as shown in Figure 24.33. The STEP system follows a conventional septic tank where the flow is pumped into a pressure forcemain.

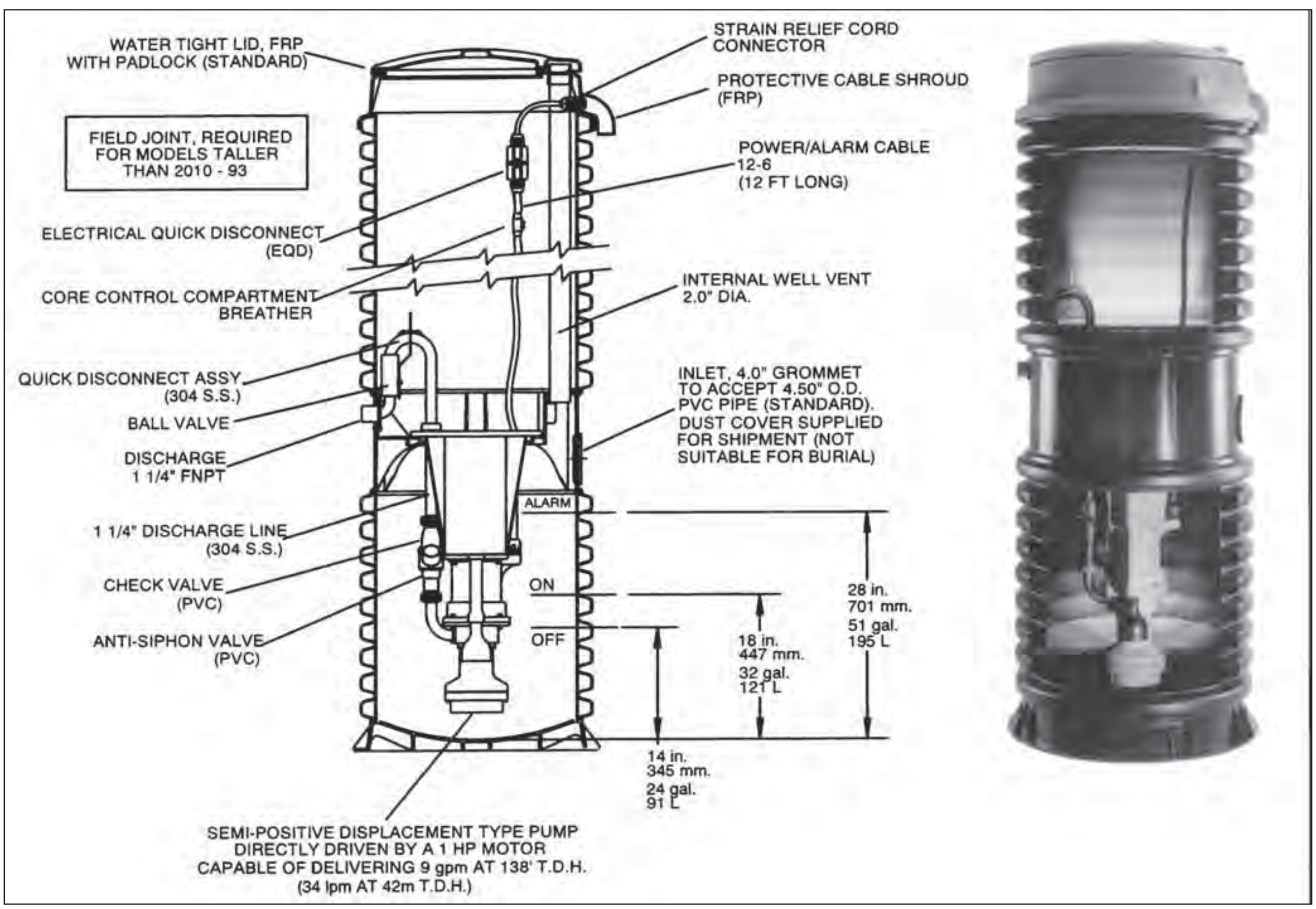


Figure 24.34 Typical grinder pump complete with housing. (Reprinted with permission from Environmental One Corp. 1994. Grinder Environment One product catalog, Schenectady, NY)

Pumping equipment for the GP technology is well developed. The pump shown in Figure 24.34 is available in several sizes and capacities to serve uses from a single-family dwelling to a small commercial or industrial flow. The unit is supplied in a prepiped and wired fiberglass enclosure that can be installed in a basement, crawl space, or below ground level in a lawn. The units are available with one or two pumps for reliability. The unit is installed and the 4-inch building sewer connected. Pumps are available for pumping against discharge heads of more than 100 ft. Pressure systems are designed similarly to forcemains, as discussed in the section on pumping stations, except for a determination of the number of pumps operating on the main at any one time and the resulting flow. GP suppliers have developed this type of statistical data, and it can be found in the respective catalog.

The normal wet well size for a single-family dwelling is 60 gallons (pump enclosure provides wet well volume). This constitutes some wastewater storage availability during periods of power outages. The units are wired to permit placing a high-water alarm at an appropriate location in the home, usually in the kitchen, so that the homeowner is made aware that the pump is not operating and that the wet well is full. The pumping units are designed for easy removal of the entire unit in case of pump failure. The pumps should give 10 or more years of service under normal conditions. It is desirable for the community with a GP system to have service provided by a utility or by a private plumbing company that will keep spare pumps in stock for rapid installation. The nonfunctioning pump is then taken to the shop for repair or replacement and kept in stock for the next replacement need. If rapid service is not available, the homeowner should install the duplex unit so that a backup pump is always available, allowing time to have the nonfunctioning unit repaired.

The septic tank effluent pressure system (STEP) is a means of eliminating the need for on-site treatment and disposal, such as the soil absorption field. In past years, septic tanks' absorption fields have been installed at locations that are no longer environmentally acceptable. Criteria for siting absorption fields have improved as more knowledge on soil percolation and potential for ground water pollution has become available. The STEP systems are being installed to eliminate failing absorption fields and as a means of providing central sewerage service to both existing and new communities. The septic tank located ahead of the pump eliminates most of the grease and solids in the flow to be pumped. The forcemain design is similar to that of the GP system except for the type of pump required. The homeowner must continue to maintain a septic tank as a part of the STEP design.

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CHAPTER 25

WATER DISTRIBUTION

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OVERVIEW OF A WATER SUPPLY SYSTEM

A water supply system includes the water supply, treatment facilities, pumping facilities, transmission lines, and local distribution network. The distribution network consists of pipes, fittings, valves, and other appurtenances designed to convey potable water at adequate pressures and discharges. Adequate discharges are necessary to cover the range of flows due to the fluctuation in demand. Adequate pressures are necessary for firefighting, general service to residents, and economic considerations such as leakage and energy losses. The pressures within a water supply system must be high enough to overcome the energy losses in the system, yet maintained below the point at which damage to fittings and other appurtenances occurs. Due to the size and varying topography within many systems, different pressure zones may be generated to ensure reliability in meeting the fluctuation in demands. These pressure zones are typically divided through booster pumping stations and storage facilities. Pressures and discharges are a function of the hydraulic characteristics of the system as well as the system's service characteristics. Service characteristics include such items as demand as it relates to present and projected population, economic base, fire flow, and climate. Hydraulic characteristics include the length, size, and condition of the pipe; types and sizes of fittings and appurtenances; and variations in elevation of the system. Since service and hydraulic characteristics constantly change, the design must incorporate allowances for these changes. Dynamic demographics of the users and deterioration of the system affect how and when the changes are made. The changes that can be made include relocating or replacing the existing waterline, increasing the pipe sizes, adding auxiliary pumps and storage, or adding more distribution lines to accommodate new development.

The water utility company is responsible for the water quality and operation of the distribution system. A water utility company can either be a public entity that, like many other public bureaus, exists for the health, safety, and welfare of the public, or it may be a privately owned utility providing water for profit. In some of the larger metropolitan and suburban areas, the water utility company heavily controls the design of a water distribution system. Personnel within the water company perform most of the design, analysis, and layout. In this case the site designers of the land development project perform only the lesser waterworks design aspects and incorporate their analyses, along with the water company's information, into the construction drawing set. In smaller locales, the analysis and design may be performed entirely by the private consultant working for the developer. Typically, the water supply company reviews the private consultant's design to ensure conformance with local standards. Regardless of whether the water supply company is public or private, the design must conform to the state health department's criteria as well as those of any other controlling public agencies. Design parameters and regulations for waterworks are available from the state board of health and the local city/county health departments. Additional information on water quality, as well as material and construction standards, are available from the Environmental Protection Agency (EPA), the American Water Works Association (AWWA), and the American National Standards Institute (ANSI).

The overall waterworks system consists of the following elements:

- The *water source,* usually a lake, river, or aquifer that serves as the municipality's main supply. Larger municipalities may have more than one source. Lakes and reservoirs are located in outlying areas where there is less pollution and the advantage of runoff from large catchments. Along rivers, water is usually extracted on the upstream side of the population centers. The minimum supply volume at the source must coincide with the present and projected demand, which it is to serve.

- A *treatment facility* to purify the water for safe use. Since pumping clean water is less expensive than pumping sediment-laden water, the location of the filtration plant should be near the source. The treatment facility treats and disinfects the water to meet the water quality standards set by government regulations. The law mandates that the water supply company provide quality potable water, and consumers expect and rely on the water company to do so.

- *Transmission lines* that convey the water leading from the source to the treatment facility as well as from the treatment facility to the distribution network. For moderate to large population areas, transmission lines can be 6 feet in diameter (and larger) and operate at pressures in excess of 200 lb/in^2. They serve as the link between the source, the treatment facility, and the distribution network. Therefore, transmission lines have limited branches and service taps.

- *Pumping facilities* that provide necessary energy to move the potable water to consumers. Pumping facilities are needed to convey the water through transmission lines to the distribution system. These pumping facilities can be simple, such as the well pumps in small systems, or they can be complex, high-capacity pumping stations needed for large municipalities. Pumping stations within the distribution network, called *booster stations,* are used to maintain required minimum pressures.

- *Intermediate storage facilities* (e.g., water tanks) that are located near the distribution network. Intermediate storage facilities stabilize the line pressures, serve as reserve for peak demand periods, and provide storage for fire flow requirements. All domestic waterline systems operate under pressure. In times of high demand, the pressure in the network is decreased, requiring the water supply to be supplemented from the storage tanks along with the water from the treatment plant. During low-demand periods, when supply pressure in the distribution lines is high, the storage tanks refill. Discounting fire flow storage, water storage volumes fluctuate 40 percent to 70 percent on a daily basis.

- *Distribution lines* that are used to link the intermediate storage facilities and the feeder lines that connect the residential, commercial, and industrial service areas. Typically, distribution networks are laid out as interconnecting loops. The looped (grid) layout allows for bidirectional flow of water. Since water travels toward the area with the lowest pressure, which is often the area of highest demand, looping delivers twice the volume of water for fire flows and other heavy demands. Additionally, grid layout allows for isolation of small areas during repairs. A branching type of configuration consists of a main feeder line with single dead-end branches to service areas. In comparison to the grid system, the branch system is not as economical for two reasons: closing down a branch for maintenance disrupts service to a larger area, and poor water quality resulting from stagnation and sedimentation in the branch ends means periodic flushing at the ends. Although dead ends cannot be avoided, they should be minimized. Fire hydrants, flushing hydrants, or blowoff valves at the dead ends allow for such periodic flushing.

- *Appurtenances* such as fire hydrants, valves, and auxiliary pumps, and fittings such as wyes, elbows, crosses, and tees that augment the operation of the distribution system. The arrangement of the appurtenances and fittings is specific to the local area they serve. Valves allow the system to isolate small service areas when repairs are needed. Other fittings are used to change flow direction and provide economic flexibility in sizing pipes.

The design of the entire system requires an evaluation of numerous factors. Location and size of main water supplies depend on general characteristics of the region such as climate, hydrology, geology, and topography. Design of treatment facilities, transmission, and distribution lines depends on existing water quality at the source, existing and projected population, and spatial distribution. Additionally, as the municipality grows, the increasing population and expanding development inevitably influence hydrologic and topographic factors as well as others that, in turn, affect water demand.

WATER USE AND DEMAND

Demand Forecasting

Water use is categorized as either consumptive use or nonconsumptive use. Consumptive use includes municipal, agricultural, industrial, and mining, whereas nonconsumptive use refers to water used for hydropower, transportation, and recreation. Water demand is the quantity that consumers use per unit of time. Land development projects involve analysis of municipal water uses such as residential, commercial, institutional, industrial, firefighting, swimming pools, and lawn and park watering.

Demand forecasting projects the future water use based on previous water use, socioeconomic trends, climatic factors, and other parameters. Various types of forecasting models may be used to estimate water demand. The least complex is a single coefficient method through which the projected demand is based on one factor such as per capita or per connection or on land use. Complex models may factor in water pricing, income, and even incorporate statistical analysis. The selection of the model depends on the type and size of the project and the availability of the data.

Part of the design of a water distribution system includes estimating the amount of water needed for a service area. Water demand for an area depends on population, climate, industry, and economic factors. Additionally, the design analysis must include fire flow requirements. Although the overall volume of water used for fighting fires is quite low relative to most other uses, the amount of water required to fight a fire, even if only for a few hours, puts a heavy strain on the system. Since fire flow requirements are so high relative to other uses, they are usually the controlling criteria in the design of distribution piping and storage. In part, the waterworks system design is based on an estimated average demand and maximum daily demand. However, variations in demand must also be included as part of the design analysis.

Variation in water use becomes apparent by considering hourly and daily individual personal water use. Each individual drinks, bathes, and generally uses varying daily amounts of water. On an hourly basis, this variation fluctuates substantially. Extend the individual fluctuations in hourly and daily use over a population of tens of thousands and it becomes apparent why water demand projection is difficult. Fortunately, individual daily use generally has an average value that exhibits only slight variations over longer periods. Variations in short-term use are further reduced as population and development stabilize. However, the capricious variables inherent in commercial, manufacturing, and agricultural industries (e.g., climate, demand for consumer goods and services) can add to wide variations in use and complicate demand forecasting.

The types of use for water demand include domestic, commercial, industrial, mining, agricultural, thermoelectric power, public use, and many others depending on where the interest is. Collecting and sorting the data to determine average use are difficult, cumbersome, and inexact. Water supply companies keep numerous records of water withdrawals and metered use. Inconsistencies in how each supplier defines various uses, or categorizes the various uses, leads to the inexactness in determining average use figures when compared over statewide areas. The point here is that it is difficult to confidently say a certain value is applicable as a blanket design value for all areas of the United States. For preliminary estimates a blanket design value is appropriate, but, for specific design, regional data is more appropriate.

An additional component of demand projection, which requires significant consideration, is the understanding and implementation of sustainability or green design goals. Water is a limited resource and all design concepts should be aware of industry trends that help to conserve this valuable commodity. Some conservation techniques include developments that do not install or permit the use of permanent landscape irrigation systems, or residential, commercial, and industrial facilities that utilize water reduction fixtures in bathrooms and kitchens. Knowledge of sustainability goals and techniques for incorporating them into design supports the conservation of this resource.

Residential Demand

Domestic water use refers to the water used for household purposes, including water for drinking, cooking, sanitary needs, landscape watering, swimming pool maintenance, street cleaning, firefighting, leakage, and system maintenance. Residential water demand widely fluctuates on both a daily and a yearly basis. Water demand has two daily peaks: once in the morning hours of 7 to 11 A.M. and another peak in the evening between 4 and 8 P.M. Although the peaks remain fixed for the time periods, the amount varies according to season and yearly rainfall. Average daily demand for domestic use ranges from 60 gallons per capita per day (gpcd) to 130 gpcd. However, studies have shown that average water use decreases as population increases.

The U.S. Geological Survey (USGS) presents data on water use in the report, "Estimated Use of Water in the United States in 1995." The data from this report shows publicly supplied domestic water use ranging from 53 gpcd in Wisconsin to 212 gpcd in Nebraska, with the average water use for all states, as well as Washington D.C., at 179 gpcd.

Commercial Demand

Commercial water use refers to the water used in motels, hotels, restaurants, office buildings, shopping centers, and other commercial establishments. Compared to residential demand, commercial demand is considerably less than residential peak demands and not as varied. Note that most of the water use for office buildings is for air-conditioning purposes. Restaurants, hotels, and motels use water mainly for cooking and cleaning. Water use estimates for design purposes are usually based on the square feet of space, potential number of occupants, or the number of water fixture units in the building. Utilizing data available in the previously noted USGS report, it can be deduced that commercial use, relative to total use, ranges anywhere from 1 percent in Iowa to nearly 41 percent in Alaska. Table 25.1 provides values for water use for various types of uses. At first glance, the values might appear to be high relative to what an individual perceives as actual use. However, these values account for unmetered water use such as firefighting, maintenance (e.g., flushing the system), leakage, and illegal connections.

Industrial Use

Industrial use accounts for the water used for fabrication, processing, washing, and cooling associated with such industries as food processing, steel production, chemical processing, mining, and petroleum refining. Note that some industry plants install their own water supply systems rather than rely on the municipal water supply. Depending on the industry and the capacity of the municipal water supply, it may be necessary for the industry to furnish its own water supply. The amount of water used varies greatly with the type of industry. A manufacturer of woolens uses 140,000 gallons per ton of woolens produced, whereas a ton of tanned leather requires 16,000 gallons. The USGS data indi-

TABLE 25.1 Daily Water Consumption Rates

TYPE OF LAND USE	WATER CONSUMPTION (GAL/DAY)
Dwellings, per person	100
High schools with showers, per person	16
Elementary schools without showers, per person	10
Community colleges per student and faculty	15
Motels @ 65 gals/person, minimum per room	120
Trailer courts @ 3 persons/trailer, per trailer	300
Restaurants, per seat	50
Interstate or through highway restaurants, per seat	180
Interstate rest areas	5
Shopping centers, per 1000 ft^2 of ultimate floor space	200–300
Theaters, auditorium type, per seat	5
Hospitals, per bed	300
Laundromats, 9 to 12 machines, per machine	500
Factories per person per 8-hour shift	15–35

(*Source:* Virginia Dept. of Health. 1993. Waterworks Regulations.)

cates that the state with the highest industrial water use (as a percent of total use) is Kentucky at 41 percent.

The wide fluctuations in water use for these three categories are evident from the data listed in Tables 25.2 and 25.3.

Other Uses

Water use can be identified with other types of manufacturing and industries. Depending on the region, the water use associated with mining, irrigation, livestock, and thermoelectric power may heavily influence design considerations for a water system. This section of the book will be concerned only with residential and commercial demand. If, however, you wish to obtain additional information on the other types of water demand, these other special uses depend on the characteristics of specific localities.

Peak Demand

Distribution system design must account for the peak periods of daily use. The maximum daily use for domestic water ranges between 1.5 and 3 times greater than the average daily use, whereas the maximum hour for domestic water use is 2 to 5 times greater than the average annual use. Since peak factors are a function of present population, population growth rate, and land use, the older stabilized areas tend to have peak factors that are 2 to 3 times lower than rapidly expanding areas. Table 25.4 shows the relationship of population on peaking factors.

TABLE 25.2 States with Highest and Lowest Water Use

	3 HIGHEST STATES (GPCD)			3 LOWEST STATES (GPCD)		
Domestic	Nevada (212)	Utah (184)	Idaho (181)	Wisconsin (53)	Ohio (54)	Pennsylvania (62)
Commercial	D.C. (90)	Nevada (81)	Utah (62)	Kentucky (7)	Texas (7)	Missouri (14)
Industrial	Alabama (62)	Kentucky (59)	Wisconsin (42)	D.C. (1)	Nevada (2)	Montana (2)
Total	Nevada (324)	Utah (269)	Washington (266)	Massachusetts (130)	Rhode Island (132)	W. VA (134)

TABLE 25.3 Public Supply Freshwater Use by State (from USGS Circular 1200)

State	Domestic (gpcd)	Commercial (gpcd)	Industrial (gpcd)	Public Use and Losses (gpcd)	Total Per Capita Use (gpcd)
Alabama	117.7	35.6	62.1	27.4	236.7
Alaska	99.7	60.3	31.5	21.0	211.6
Arizona	134.2	34.4	16.8	20.7	206.1
Arkansas	96.5	29.0	28.5	36.5	190.5
California	121.6	32.6	9.3	20.6	184.1
Colorado	141.9	29.8	5.6	29.6	203.8
Connecticut	75.5	35.2	16.6	27.7	154.9
Delaware	76.2	35.5	28.4	19.5	159.6
D.C.	171.5	90.3	1.3	0	263.1
Florida	103.3	31.6	8.4	25.6	168.9
Georgia	106.6	28.5	32.9	27.3	195.3
Hawaii	117.0	42.0	5.0	27.7	191.7
Idaho	180.8	23.1	8.6	29.5	241.9
Illinois	90.0	42.3	11.4	31.2	174.8
Indiana	76.2	27.8	29.2	23.1	156.3
Iowa	64.7	30.2	36.3	40.9	172.1
Kansas	82.3	28.9	16.0	32.0	159.2
Kentucky	69.9	6.9	58.6	12.5	147.9
Louisiana	121.6	14.3	9.1	20.8	165.7
Maine	65.0	35.3	19.8	19.8	139.8
Maryland	103.8	20.4	10.6	65.0	199.8
Massachusetts	64.9	33.7	15.4	15.8	129.8
Michigan	90.3	36.7	39.1	22.3	188.4
Minnesota	71.6	30.8	12.3	30.8	145.5
Mississippi	109.7	14.6	8.9	17.7	150.9
Missouri	86.4	13.6	32.3	28.9	161.2
Montana	119.4	40.3	1.6	60.5	221.7
Nebraska	120.2	61.3	20.2	20.2	221.7
Nevada	212.5	80.6	1.5	29.2	323.8
New Hampshire	81.8	30.1	18.7	9.6	140.2
New Jersey	77.6	25.8	13.1	29.3	145.9

TABLE 25.3 (*Continued*)

State	Domestic (gpcd)	Commercial (gpcd)	Industrial (gpcd)	Public Use and Losses (gpcd)	Total Per Capita Use (gpcd)
New Mexico	136.2	56.5	10.9	21.7	225.4
New York	111.7	25.3	22.0	26.2	185.1
North Carolina	69.9	29.1	40.6	22.1	161.7
North Dakota	81.8	30.7	5.1	30.7	148.3
Ohio	53.6	38.3	38.3	23.0	153.2
Oklahoma	82.3	58.0	41.6	11.6	193.5
Oregon	135.8	36.7	33.0	28.8	234.4
Pennsylvania	61.8	24.1	21.3	63.4	170.6
Rhode Island	64.9	22.8	13.7	29.6	131.0
South Carolina	135.3	18.4	16.2	29.8	199.6
South Dakota	86.4	34.9	13.1	11.8	146.2
Tennessee	80.3	48.2	29.4	17.7	175.8
Texas	139.2	7.4	15.2	23.4	185.2
Utah	183.8	62.2	9.2	13.5	268.7
Vermont	82.6	24.4	24.4	17.5	148.9
Virginia	85.5	30.7	17.7	24.4	158.3
Washington	127.6	36.3	74.7	27.5	266.1
West Virginia	72.7	17.4	10.6	33.3	134.1
Wisconsin	53.1	31.2	42.4	41.6	168.3
Wyoming	157.0	46.5	7.0	49.4	259.9
AVERAGE USE	101.8	30.0	21.4	26.2	179.4

(*Source:* U.S. Geological Survey. 2000. Estimated Water Use in 1995.)
The authors of this handbook understand that more recent data has been released for USGS Circular 1200 data from 2000 that may be more relevant as to the actual usage in different areas of the country. However, due to modifications in the collection and reporting methodology, it is difficult to decipher usage specific for the purposes of this handbook. Therefore, the 1995 data is utilized to provide an understanding of demands and completion of design examples. All professionals are encouraged to contact the local jurisdictional agency to gain an understanding of project-specific usage when completing actual design computations and projections.

Typically, distribution lines are sized for design flows of maximum daily consumption plus the required fire flow. However, if the maximum daily consumption plus fire flow is less than the estimated maximum hourly amount, the design may be based on the latter value. Local regulations and state waterworks design manuals dictate minimum design flows.

Since the estimated water use design values are based on immediate as well as future expectations in growth and development, economic assessments are made to determine the long-range plan of the system. The decision may be to design the system for the short-term future and improve the system later rather than size and build the system for long-range future projections.

DESIGN REQUIREMENTS

Pressure Requirements

Pressure requirements in the system depend on the combined normal service requirements and fire flow demand. Pressures must be high enough to overcome energy losses within the distribution and service lines as well as the losses incurred from hydrants, nozzles, hoses, and other firefight-

TABLE 25.4 Estimated Peak Ratios for Residential Water Systems

Population	Ratio of Maximum day to average annual use	Ratio of Maximum hour to average annual use
0–500	3.0	4.50
500–1000	2.75	4.13
1000–2000	2.50	3.75
2000–3000	2.25	3.38
3000–10,000	1.90	2.85
10,000–25,000	1.80	2.85
25,000–50,000	1.80	2.70
50,000–75,000	1.75	2.62
75,000–150,000	1.65	2.48
over 150,000	1.50	2.25

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(*Source:* Recommended Guidelines for Residential Servicing in Ontario. 1973. Ontario Housing Advisory Committee.)

ing equipment. Additionally, pressure requirements are a function of the topography. Since most waterlines are installed at minimum depth, they closely follow the ground surface topography. Consequently, pressures in the system must be increased in the hilly service areas to overcome elevation differences. A balance must be struck between the pressures required for normal service operations and the pressures required for short-term high-demand and emergency occasions. Although the water supply system can be designed to operate at higher pressures, sustained excessive pressures add to system costs by increasing leakage volumes and potential damage to fixtures. To address fluctuations in pressure due to extreme topography changes and demands over a large area, some water distribution systems divide into different pressure zones to maintain reliability with the supply. These pressure zones allow the system to provide varying pressure ranges in different locations, but require some form of mechanical equipment, such as booster pumps, to move the water supply between the different zones.

A municipality's exact pressure requirements are established by a state agency, such as the health department, with supplemental requirements imposed by agencies within the municipality such as the fire marshal. Typically, street water main pressures of 20 lb/in^2 are the minimum when providing either maximum daily demand (including fire flow requirements) or the peak hour demand. This is a precautionary measure, designed to prevent potential cross-connection backflows from house fixtures. This minimum pressure also represents the minimum pressure required to overcome frictional losses in the service line and push the water up three stories, the upper height limit typical in residential areas.

Preferable normal pressures in the street should be between 40 lb/in^2 and 60 lb/in^2 in residential areas. In most cases, a pressure of about 80 lb/in^2 is recommended as the upper limit. Above 80 lb/in^2, special pressure-reducing valves may be necessary to prevent residential fixture damage. Typically, commercial areas require a minimum pressure of 75 lb/in^2. Booster pumps for tall buildings (e.g., more than 10 stories) eliminate the need for excessively high pressures in the street mains.

Fire Flow Requirements

Each municipality establishes its own parameters for fire flow requirements based on local conditions, although the municipality may instead refer to the fire flow recommendations provided by the Insurance Services Office (ISO). The ISO recommends criteria for establishing insurance rates and for classifying municipalities with reference to their fire defenses and physical conditions. The criteria provide a means for rating a municipality based on type of firefighting equipment, proximity of equipment, water distribution flows, storage, and other factors. One such document by the ISO is the "Guide for Determination of Required Fire Flow." Although the guide only recommends fire flows, many areas defer to it for fire flow considerations while others have established their own requirements. Minimum fire flows vary widely among jurisdictions. The design engineer should consult with the local water authority and fire marshal's office for specific criteria.

Estimating Fire Flow

The ISO uses the following equation to estimate the required fire flow:

$$F = 18 \times C \times \sqrt{A} \tag{25.1}$$

where F = required fire flow in gpm, C = coefficient related to the type of construction, and A = total floor area in ft^2 including all stories but excluding basements.

For fire-resistive buildings, consider the six largest successive floor areas if the vertical openings are unprotected; if the vertical openings are properly protected, consider only the three largest successive floor areas. Coefficient $C = 1.5$ for wood frame construction, 1.0 for ordinary construction, 0.9 for heavy timber type buildings, 0.8 for noncombustible construction, and 0.6 for fire-resistive construction. Coefficients should not be greater than 1.5 nor less than 0.6 and may be determined by interpolation. Such interpolation should be between the consecutive types of construction just noted. Additionally, these guides recommend a minimum fire flow of 500 gpm and maximum fire flows under the following conditions: 8000 gpm for wood frame construction, ordinary, and heavy timber construction; 6000 gpm for noncombustible construction and fire-resistive construction. For normal one-story building of any type construction, the fire flow should not exceed 6000 gpm. Table 25.5 identifies required fire flows for areas of single-family and small two-family dwellings not exceeding two stories in height.

Adjustments to recommended fire flow values might be applicable for certain occupancy conditions. Equation 25.1 may be reduced up to 25 percent for occupancies having a low fire hazard or increased up to 25 percent for occupancies having a high fire hazard. Examples of occupancies considered low fire hazard are residential dwellings, churches, schools, hotels, hospitals, and other public buildings. Occupancy of high fire hazard are manufacturing and processing plants using explosives and high combustibles such as oil refineries, paint shops, and aircraft hangers. Other modifications that affect the required fire flow rate include the existence of sprinkler systems, noncombustible construction, and building separation. However, the range of adjustment to the initial fire flow estimates cannot be greater than 75 percent and the final adjusted flow cannot be less than 500 gpm nor exceed 12,000 gpm.

TABLE 25.5 Required Fire Flows for Single-Family and Small Two-Family Dwellings

Distance between buildings (ft)	Suggested required fire flow (gpm)
Over 100	500
31–100	750–1000
11–30	1000–1500
10 or less	1500–2000*

*If the buildings are continuous use a minimum of 2500 gpm. Where wood shingle roofs could contribute to spreading fires, add 500 gpm.
(From the publication "Guide for Determination of Required Fire Flow," 2nd ed. Reprinted with the permission of Insurance Services Office, Inc. Copyright 1974.)

Fire flow estimates resulting from applying these criteria are only a guide and warrant the judgment of experienced and knowledgeable persons in fire protection. Typically, local jurisdictions require fire flow approval by controlling agencies such as the fire marshal's office, public water supply agency, and health department. Exact requirements by local jurisdictions for fire flows may not be the same as what is recommended by the ISO. In fact, there can be a wide range of fire flow requirements even among adjacent jurisdictions.

Fire Flow Tests

Before new projects ultimately get approval for construction by the fire marshal's office, fire flow tests are performed to determine the fire flow capacity and adequacy of the existing system. Fire flow tests are used to determine available flow rates and pressures at various locations for firefighting purposes. Although the water utility company has extensive data on the existing water system in the larger municipalities, uncertainties in the hydraulic variables and service variables require further data to corroborate existing information. On commercial sites and small subdivisions, the test is performed on hydrants near the point where the proposed water main will connect to the existing water main. On larger sites, where the project is built in phases, fire flow tests may be required near the connection points at each subsequent phase of the development.

The following discussion on testing procedures and analysis is extracted from the National Fire Protection Association (NFPA). The exact method and analysis may deviate according to local regulations.

The test consists of discharging water at a measured flow rate from one or more hydrants and observing the resulting pressure drop in the main through another fire hydrant. When delivering fire flows, a minimum residual pressure of 20 lb/in^2 in the main is typically required for two basic reasons: First, fire department pumpers require 20 lb/in^2 in order to operate effectively, and second, a minimum residual pressure is needed to prevent a vacuum (negative pressures) from developing in the system that can cause collapse of pipes and inadvertent back siphonage of polluted water.

For the test, one base point hydrant is selected as the residual hydrant. The hydrants to be flowed are between the residual hydrant and the larger mains. Typical patterns for selecting the test hydrants are illustrated in Figure 25.1. The residual pressure at this location is measured before other hydrants are opened. The pressure at this location is then determined when the other hydrants are fully opened. The test is made during a period of ordinary demand such that the pressure drop in the residual hydrant is 25 percent or less of what it would be at the total demand necessary for firefighting purposes.

A pressure gauge is placed on one of the hose outlets on the residual hydrant, and the hydrant valve is fully opened.

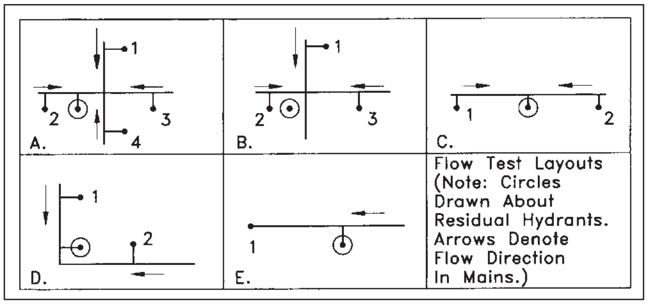

Figure 25.1 Suggested test layout for hydrants. (From the publication "Grading Schedule for Municipal Fire Protection." Reprinted with the permission of Insurance Services Office, Inc. Copyright 1974)

After the barrel air is exhausted, the pressure is recorded. The other hydrants are opened full in succession, one at a time. After each hydrant is opened and the flow stabilized, the pressure is recorded at the residual hydrant and the discharge at each open hydrant is measured using a pitot gage. The discharge Q (gpm) is determined from

$$Q = 29.83\, cd^2 \sqrt{p} \tag{25.2}$$

where c is the coefficient of discharge of the pitot tube (depends on the manufacturer specifications, typically around 0.9), d is the diameter of the outlet hose connection in inches, and p is the velocity pressure in lb/in^2 (i.e., the pitot tube reading).

After all observations are recorded, the discharge (in gpm) at the specified residual pressure or for any pressure drop is

$$Q_R = Q_F \times \left(\frac{h_r}{h_f}\right)^{0.54} \tag{25.3}$$

where Q_R = flow predicted at the desired residual pressure, Q_F = total flow measured during the test, h_r = pressure drop to the desired residual pressure, and h_f = pressure drop measured during test.

As the equation is written, any consistent units for the Q's and h's will work.

Fire Duration Requirements

In addition to providing adequate discharges and pressures for normal consumption, a water supply system must be designed to provide water for sustained periods for firefighting purposes. Since the magnitude, duration, location, and frequency of a fire are quite unpredictable, the design of a system should be based on a reasonable worst-case scenario.

The ISO defines the average daily consumption as the total amount of water used each day during a 1-year period considered as a rate for a 24-hour period. The maximum daily consumption is defined as the maximum total amount used during any 24-hour period in a three-year period, disregarding any unusually high circumstantial amounts caused by filling storage tanks. An adequate water supply, according to the ISO, can deliver the required fire flow for the duration given in Table 25.6 at the maximum daily rate.

Distribution Storage

Distribution storage, which consists of small reservoirs located near service areas, acts as service storage to compensate for the widely fluctuating demands and provides storage for firefighting and for emergency reserve. Distribution storage is used to normalize operating pressures, eliminate the need for nonuniform pumping, reduce the need for constructing large mains at the periphery of the system, and provide increased reliability for fire protection and other emergencies.

Whether ground storage or elevated storage tanks are used depends on such factors as topography, size of service area, reliability of main water supply, and economics. Auxiliary pumps at the ground storage facility or higher water surface elevations in the elevated storage reservoir can be utilized to equalize pressures during high-demand periods. Since short and frequent high-demand periods can require pumps to turn on and off regularly to maintain system pressures, one advantage to elevated storage tanks (over auxiliary pumps) is the ability to supply a sustained pressure without the cyclic pump operations. However, the selection of the type of distribution storage should be considered on a case-by-case basis.

Although the need for design and construction of storage facilities is infrequent in moderately sized land development projects, very large projects or areas of unanticipated rapid growth may warrant distribution storage facilities. Nonetheless, the project engineer should be aware of the major factors governing the design of the facilities. In many cases, an engineer specializing in the design of waterworks will be

TABLE 25.6 Required Fire Flow Duration

Required fire flow (gpm)	Required duration (hr)
10,000 and greater	10
9500–9000	9
8500–8000	8
7500–7000	7
6500–6000	6
5500–5000	5
4500–4000	4
3500–3000	3
2500 and less	2

(*Source:* Virginia Dept. of Health. 1993. Waterworks Regulations.)

called on to perform the specific design. In the projects where such facilities are required, the developer and jurisdiction may enter into some kind of joint venture where the costs would be shared by the two. This practice is common in instances where users beyond the project boundaries would share the facility.

The size of a storage tank depends on the characteristics of the service zone, fire demand requirements, and the local standards governing such design. A general rule-of-thumb storage requirement is given as one day's supply plus fire flow. The one-day supply is based on the maximum day usage, while the fire flow storage is based on the duration as suggested by the ISO for the design fire flow (see Tables 25.5 and 25.6). Note that local design standards may supersede this method of storage demand design. Preferably, the tank should be sized to provide two to three days' supply, although economic and risk analysis will dictate the upper limit of the size.

Another consideration for storage tank sizing deals with the retention time of the water in the tank. Since a storage tank is designed to supplement the added demand during peak periods and refill during off-peak periods, a properly designed tank under most operating conditions never completely empties. However, due to this fluctuation, there is a somewhat continuous exchange of water within the tank. With the residual effects of disinfectant chlorine limited to six to ten days, the maximum residence time of water in the tank should be less than eight days to prevent stagnation and other health problems.

Formal design of a storage facility should incorporate the hourly use hydrograph or mass diagram for the maximum day. A description of the design can be found in most basic water resource textbooks. One way to estimate storage requirements based on land use follows.

EXAMPLE 1

Table 25.7 shows the land use for a new service area and the corresponding demand for the average day for the type of land use. For this service area, fire flow requirements are 4 hours' duration for a flow of 2500 gpm. Local ordinance requires a reserve of 20 percent of the maximum day demand, and the maximum day demand is assumed to be equal to 1.6 times the average day demand. Use a t factor of safety = 1.25. What are the storage requirements, given these parameters?

Storage Required:

$$\text{4-hour fire flow @ 2500 gpm} \times 60\ \text{min/hr} = 600{,}000\ \text{gal} \tag{25.4}$$

$$2{,}068{,}910\ \text{gal} \times 1.6 \times 0.20 = 662{,}051\ \text{gal}$$

$$\text{Subtotal} = 1{,}262{,}051\ \text{gal}$$

$$\begin{aligned}\text{Storage} &= 1{,}262{,}051 \times (1.25)\\ &= 1{,}577{,}564\ \text{gal}\end{aligned}$$

Further considerations in this analysis would be to determine whether one or several facilities would supply the required storage, the size of each facility, and the location.

TABLE 25.7 Demand Requirements for New Service Area (Example 1)

LAND USE	UNIT OF MEASUREMENT	NO. OF UNITS	AVERAGE DEMAND (GPD)	TOTAL DEMAND (GPD)
Single-family detached	per dwelling	1682	350	588,700
Town house	per dwelling	519	350	181,650
School	per student	750	16	12,000
Daycare center	per student	200	16	3200
Recreation center	per person	1528	10	15,280
Hotel	per room	120	168	20,160
Restaurant	per seat	800	50	40,000
High-rise commercial	per acre	89.1	2000	1,782,000
Low-rise commercial	per acre	362	1500	543,000
			Subtotal =	1,582,190
Existing demand				486,720
			TOTAL =	2,068,910

PUMPING FACILITIES

Pumping facilities are necessary to transport treated water through the transmission and distribution lines to fill storage tanks and maintain system pressure. For small water utilities, the well pump or the single finished water pumping arrangement at a treatment plant may be all that is required. For large municipal distribution systems, a complex network of pumping stations, monitored and controlled from a central point, may be needed.

Pump Selection

Small water utilities commonly employ three types of pumps for water distribution service: centrifugal, positive displacement, and jet (ejector).

Centrifugal Pumps. Centrifugal pumps are the most commonly used of the three. A centrifugal pump involves a casing containing a rotating impeller mounted on a shaft turned by a motor power source. Water that enters the suction side of the rotating impeller is thrown at high velocity against the casing to convert velocity head into pressure. Centrifugal pumps can be designed to provide stages in series, where each impeller and matching casing constitutes a stage to realize pressures not attainable with a single-stage pump. Pumps having more than one stage are called multistage pumps, of which there are two types—submersible pumps and turbine pumps.

The submersible pump consists of one or more pump stages driven by a closely coupled motor designed for submerged operation (see Figure 25.2). They are commonly used in wells, but may also be used in finished water clear wells at treatment facilities.

Turbine pumps consist of one or more centrifugal pump stages driven by a vertical shaft, connecting the pumping assembly to a motor mounted at the surface. Figure 25.3 shows a turbine pump used for well service. Turbine pumps in this configuration are called vertical turbine pumps. Turbine pumps can also be mounted on treatment plant clear wells for distribution of finished water.

Positive Displacement Pumps. Positive displacement pumps, as the name implies, displace a set volume of water with each turn of the pump. The pumping rate varies with the speed of the pump. Although these pumps are not that common in water distribution service, especially in high-volume applications, they are well suited for intermittent pumping at high pressure. Positive displacements pumps are available in several configurations:

Reciprocating pumps: This pump consists of a plunger driven back and forth in a closely fitted cylinder with check valves at both the inlet and the pump outlet.

Helical rotor pump: The helical pump consists of a spiral rotor that rotates in a sleeve. As the spiral rotor turns, it traps water between the rotor and the sleeve, forcing it to the outlet end of the sleeve.

Rotary gear pump: This type of pump uses two meshing gears housed in a sealed casing that traps water in cavities between them. As the gears mesh, they carry water from the inlet to outlet port.

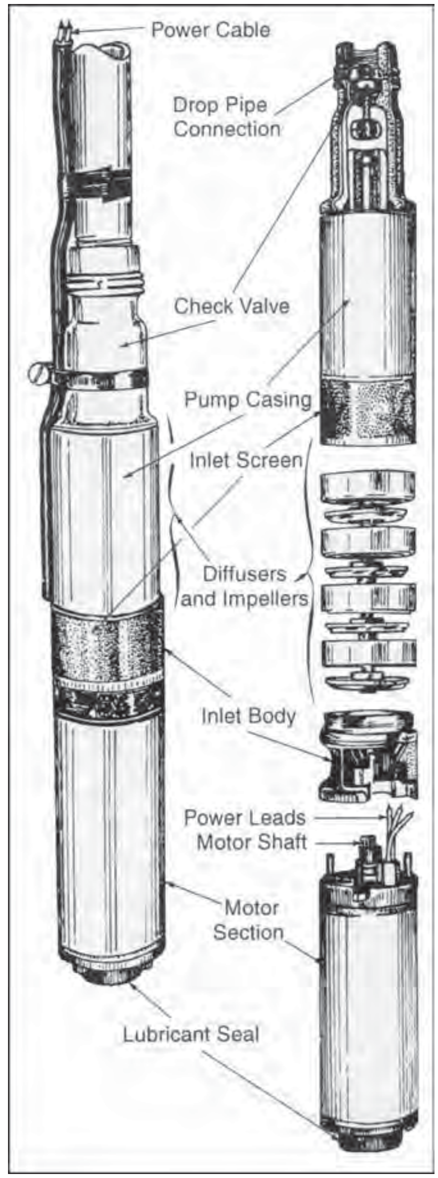

FIGURE 25.2 View of a multistage submersible pump. (Reprinted from *Design and Construction of Small Water Systems,* by permission. Copyright © 1999, American Water Works Association).

Jet (Ejector) Pumps. Jet pumps are actually a combination of centrifugal and ejector pumps (see Figure 25.4). A portion of the centrifugal pump discharge is diverted through a nozzle and venturi tube near the water level of the source. This creates a low-pressure zone that draws flow upward toward the surface, where the centrifugal pump suction can further lift it into the distribution system. These jet installations are economical for low-volume facilities, and are commonly used in wells.

The fundamental considerations for pump selection within a particular installation are as follows:

- Yield of the well, or other water source
- Total daily needs and instantaneous demand of the system

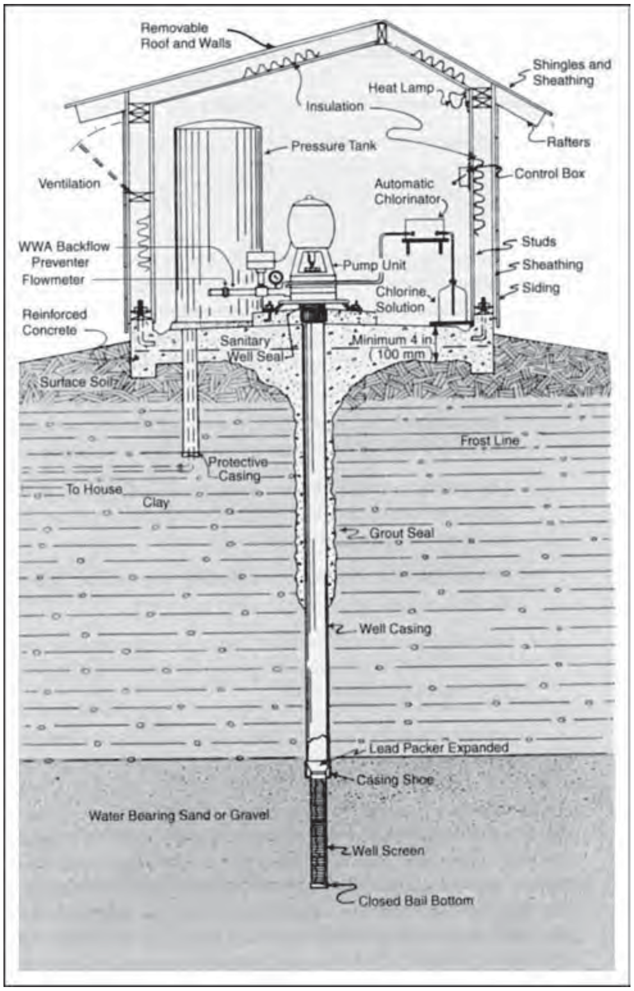

FIGURE 25.3 Turbine pump in well service. (Reprinted from *Design and Construction of Small Water Systems,* by permission. Copyright © 1999, American Water Works Association).

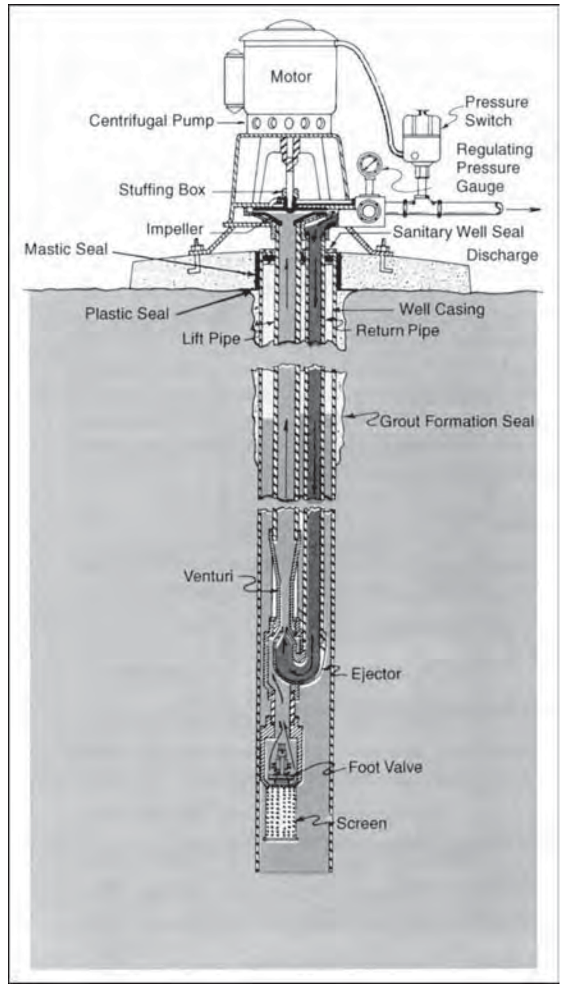

FIGURE 25.4 Combined centrifugal and ejector pump. (Reprinted from *Design and Construction of Small Water Systems,* by permission. Copyright © 1999, American Water Works Association)

- Total operating head pressure of the pumps at normal delivery rate, including lift and all friction losses
- Elevation difference between the ground level and the water level in the well during pumping
- Availability of power
- Ease of maintenance and availability of parts
- Initial and operations costs
- Reliability of pumping equipment

Table 25.8 provides information useful for selecting the type of pump needed for typical small system applications. Selecting the proper pumping unit size must be done by carefully evaluating the peak demand, available storage in the system, and capacity of the water source. Increased storage capacity is needed when source yield is low in comparison with peak demand (as often happens with well sources). This is necessary to avoid starting and stopping pump motors more than four or five times per hour in order to maintain optimum service life of the equipment.

System Head Curve

The system head curve is an essential tool for use in determining the pump's type, size, and number of units to be applied for the most economically feasible installation. It graphically presents hydraulic head requirements for various flow characteristics of a particular system, making it easier to determine the appropriate configuration. Figure 25.5 shows an example of system head curve including a typical centrifugal pump curve.

The concept of total dynamic head must be understood to construct a proper system head curve for a potable water distribution pumping system. Figure 25.6 is a graphical representation of total dynamic head for a well pump installation. Static head, friction head, and pressure head are the three components of total dynamic head. Static head is the difference in elevation of the source water and the point of discharge. Friction head is the loss that occurs due to valves, fittings, and piping (discussed later in this chapter under "System Analysis, Minor Losses"). The pressure head includes the velocity head as well as the minimal residual pressure required in the system by state health departments (usually no less than 25 lb/in^2 at the outlet fixture).

TABLE 25.8 Specifications for Various Types of Pumps

Type of Pump	Practical suction lift*	Usual well-pumping depth	Usual pressure heads	Advantages	Disadvantages	Remarks
Reciprocating:						
Shallow well	22–25 ft (7–8 m)	22–25 ft (7–8 m)	100–200 ft (30–60 m)	Positive action Discharge against variable heads	Pulsating discharge Subject to vibration and noise	Best suited for capacities of 5–25 gpm (19–95 L/min) against moderate to high heads
Deep well	22–15 ft (7–8 m)	Up to 600 ft (183 m)	Up to 600 ft (183 m) above cylinder	Pumps water containing sand and silt Especially adapted to low capacity and high lifts	Maintenance cost may be high May cause destructive pressure if operated against closed valve	Adaptable to hand operation Can be installed in very small diameter wells (2-in [51-mm] casing)
Centrifugal						
Shallow well Straight centrifugal	20 ft (6 m) maximum	10–20 ft (3–6 m)	100–150 ft 30–46 m)	Smooth, even flow Pumps water containing sand and silt Pressure on system is even and free from shock Low starting torque Usually reliable; good service life	Loses prime easily Efficiency depends on operating under design heads and speed	Very efficient pump for capacities above 60 gpm (227 L/min) and heads up to about 150 ft (46 m)
Regenerative vane turbine type (single-impeller)	28 ft (7 m) maximum	28 ft (7 m)	100–200 ft (30–60 m)	Same as straight centrifugal except not suitable for pumping water containing sand or silt Self-priming	Same as straight centrifugal, except maintains priming easily	Reduction in pressure with increased capacity not as severe as with straight centrifugal
Deep well						
Vertical line shaft turbine (multistage)	Impeller submerged	50–300 ft (15–91 m)	100–800 ft (30–244 m)	Same as shallow-well turbine All electrical components are accessible aboveground	Efficiency depends on operating under design head and speed Requires straight well large enough for turbine bowls and housing Lubrication and alignment of shaft critical Abrasion from sand	
Submersible turbine (multi-stage)	Pump and motor submerged	50–400 ft (15–122 m)	50–400 ft (15–122 m)	Same as shallow-well turbine Easy to frostproof installation Short pump shaft to motor Quiet operation Well straightness not critical	Repair to motor or pump requires pulling from well Sealing of electrical equipment from water vapor critical Abrasion from sand	3500 RPM models, although popular because of smaller diameters or greater capacities, are more vulnerable to wear and failure from sand and other causes
Jet						
Shallow-well	15–20 ft (5–6 m) below ejector	Up to 14–20 ft (5–6 m) below ejector	80–150 ft (24–46 m)	High capacity at low heads Simple operation Does not have to be installed over the well No moving parts in well	Capacity reduces as lift increases Air in suction or return line will stop pumping	
Deep Well	15–20 ft (5–6 m) below ejector	25–120 ft (8–37 m) 200 ft (61 m) maximum	80–150 ft (24–46 m)	Same as shallow-well jet Well straightness not critical	Same as shallow-well jet Lower efficiency, especially at greater lifts	The amount of water returned to ejector increases with increased lift—50% of total water pumped at 50-ft (15 m) lift and 75% at 100-ft (30 m) lift
Rotary						
Shallow-well (gear type)	22 ft (7 m)	22 ft (7 m)	50–250 ft (15–76 m)	Positive action Discharge constant under variable heads	Subject to rapid wear if water contains sand or silt Wear of gears reduces efficiency	
Deep-well (helical rotary type)	Usually submerged	50–500 ft (15–152 m)	100–500 ft (30–152 m)	Efficient operation Same as shallow well rotary Only one moving pump device in well	Same as shallow-well rotary, except no gear wear	A cutless rubber stator increases life of pump Flexible drive coupling has been weak point in pump Best adapted for low capacity and high heads

*Practical suction lift at sea level. Reduce lift 1 ft (0.3 m) for each 1,000 ft (305 m) above sea level.

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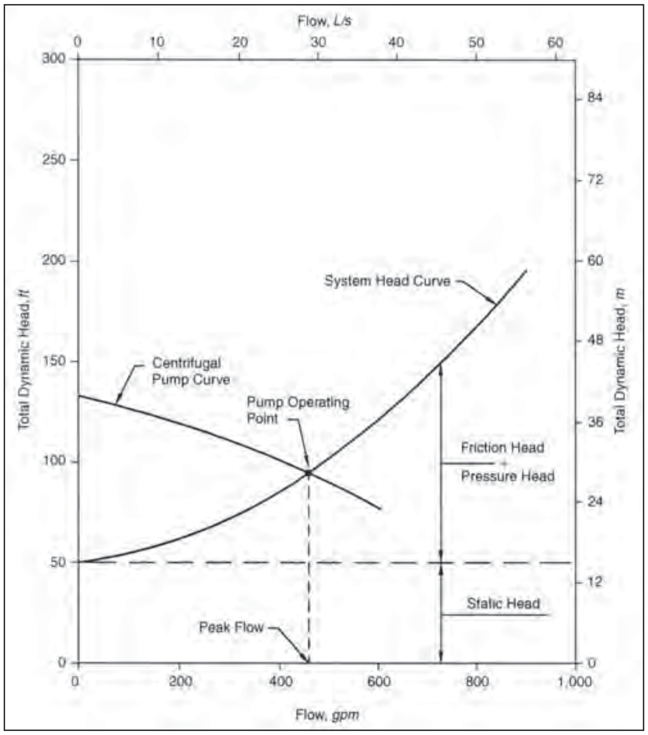


FIGURE 25.5 System head curve. (Reprinted from *Design and Construction of Small Water Systems,* by permission. Copyright © 1999, American Water Works Association)

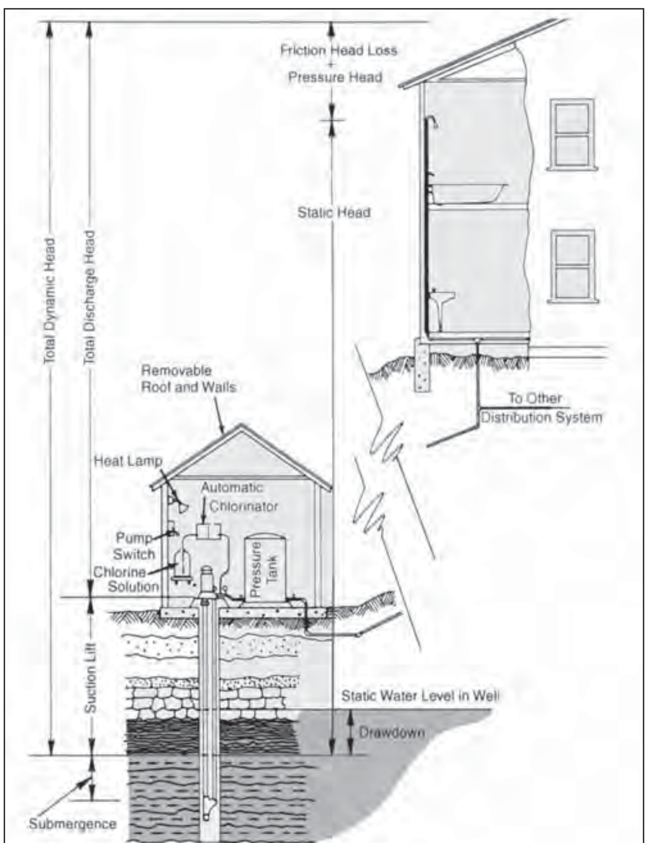


FIGURE 25.6 Components of total dynamic head in well pump. (Reprinted from *Design and Construction of Small Water Systems,* by permission. Copyright © 1999, American Water Works Association)

Water hammer, or hydraulic surge, occurs when water flowing in a pipe comes to an abrupt stop. A common example of this is when a pump shuts off suddenly due to a power failure. On such an occasion, the resulting surge can cause system pressure that is many times the normal working pressure. These high pressures, if not adequately accounted for in the design, can damage piping, valves, and pumping equipment. Lack of proper surge protection can result in catastrophic failure, requiring several days of repair while the utility customers are without water service. Surge protection must be carefully designed, even for small water utilities. Common surge protection methods include surge relief valves and pressure surge tanks located on the discharge main near the pumps and vacuum relief valves located at key points on long forcemains.

Pump Drives

Pumps in the water utility industry are normally driven by alternating current (AC) motors. The power source for AC motors can be single-phase or three-phase. However, single-phase is generally limited to small motors of 10 hp (0.75 kW) or less. On a first cost basis, establishing a three-phase power source for a pumping facility is more expensive than it is with single-phase, although the three-phase is more efficient.

AC motors can be provided as squirrel-cage, synchronous wound, or wound-rotor induction types. However, squirrel-cage inductor types are most commonly used because they are less expensive than the other two and they have proven operation. In general, lower-speed motors are larger and more expensive than higher-speed motors, but they have a longer service life. Normally, the needs of small water utilities can be met through properly designed constant-speed pumping arrangements of multiple pumps. However, two-speed squirrel-cage motors are available.

Note that fairly recent improvements in technology, reliability, and costs of variable-frequency drives (VFDs) make them worthy of consideration for small utility service. VFDs work by converting AC to DC and then back to AC but at a different frequency. Since the speed of a synchronous motor is directly proportional to frequency, varying the frequency varies the motor speed. Because of this conversion process, VFDs produce considerable heat that must be properly vented or even addressed by the use of air conditioning.

Packaged Booster Stations

Packaged booster pumping stations are very popular with small water utilities because of their economy and ease of installation. These units, which are delivered to the construction site already assembled, complete with controls and electrical, can be installed with minimal labor and time. Although these packaged pumping units can be used for primary finished water service at treatment plants, they are more often used as booster stations out in the distribution system. These packaged stations can be ordered for either above- or below-ground-level installations, as shown in Figures 25.7 and 25.8, respectively.

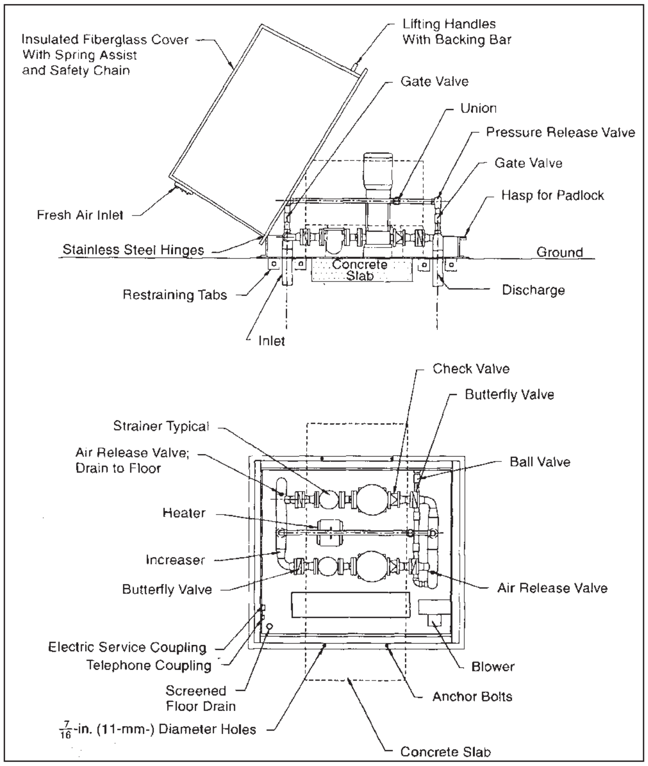


Figure 25.7 Aboveground packaged booster pump station. (Reprinted with permission of Universal Sanitary Equipment Manufacturing Co., Tumah, WI)

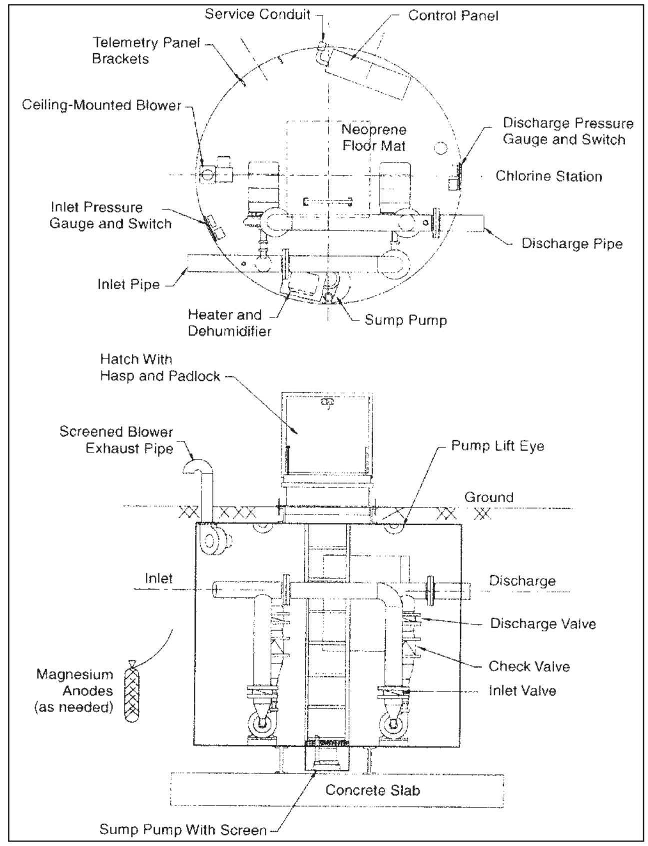


Figure 25.8 Below-ground packaged booster pump station. (Reprinted with permission of Universal Sanitary Equipment Manufacturing Co., Tumah, WI)

Emergency Power

Electrical power to a treatment facility or pumping station can be disrupted by a storm or other natural disaster for many hours or even for days. Many state health departments require that critical waterworks and pumping stations be protected against power failure by a standby power source. Normally, the standby power source is a connection to a second independent public power source (served by a separate power grid that serves the primary source) or a standby generator set.

As a minimum, generator sets should be sized to provide power for the average system demand plus basic lighting and heating. Generator sets must be maintained and regularly exercised to ensure that they will operate properly when called upon during an emergency. Although these sets normally operate on diesel fuel, units can be obtained that operate on propane, liquefied natural gas, or natural gas, if available. Both the generator set and its auxiliary fuel tanks must be properly secured against vandalism, and the fuel tank and its feed lines must be contained to prevent contamination from leakage.

There are several available options for securing and containing the generator set and its fuel tank. The first option is a custom-designed, built-in-place building. The advantages of such a building are that it can match the aesthetics of nearby buildings and surroundings and can provide ideal conditions for maintenance and repair of the set. Care must be taken to properly ventilate the building to prevent air starving of the operating generator set. This is typically done with properly sized louver systems that are opened either by the force of the air being pulled toward the generator set or by electric motors that activate when the generator set is started.

Generator sets can also be provided by the manufacturer with a sound-attenuated enclosure made of steel or fiberglass, with removable panels to enable repairs (see Figure 25.9). The disadvantage of this is that the repair personnel must

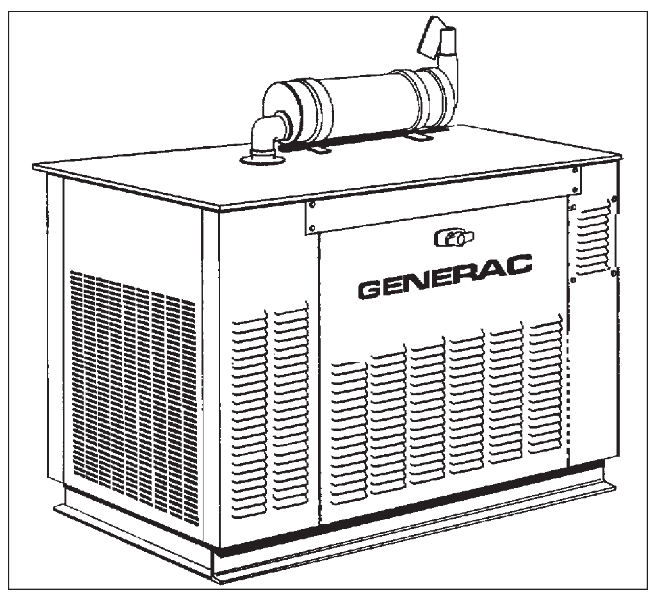


Figure 25.9 Sound attenuated walkin enclosure. (Reprinted with permission of Copyright © Tramont Corporation 2001)

stand in the elements to do their work. To facilitate repair, the generator manufacturer can also provide a sound-attenuated shelter to cover the set and provide space for repairs to be done under protected conditions. These shelters are essentially small prefabricated buildings made of steel or fiberglass that fit compactly over the set, with clearances to allow repairs out of the weather. They are generally less costly than custom-designed buildings, but are more costly than a simple generator set enclosure (see Figure 25.10).

FIGURE 25.10 Typical generator enclosure. (Reprinted with permission of General Power Systems, Wakesha, WI)

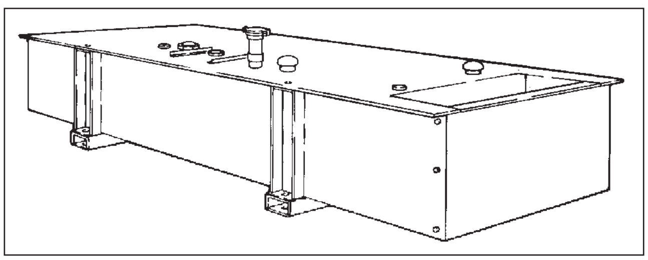


FIGURE 25.11 Skid-mounted fuel tank for location beneath a generator set. (Reprinted with permission of Cummins Power Generation)

Until recently, the normal arrangement for fuel tanks serving generator sets was to use buried tanks. However, as with buried tanks serving gasoline stations, there have been many instances when failure of the tanks and their feed lines causes contamination of the surrounding soils and ground water. Buried tanks are still a viable option, but they must meet much higher standards concerning leak monitoring and double-walled containment for the tank and buried lines (state and local regulatory agencies can provide detailed standards for buried tank installations). Because this has greatly increased the cost of buried tanks, most public utilities are choosing other options.

The other available options for nonburied fuel tanks are aboveground tanks in buildings that are otherwise protected. One approach is to use a protected skid-mounted tank that is

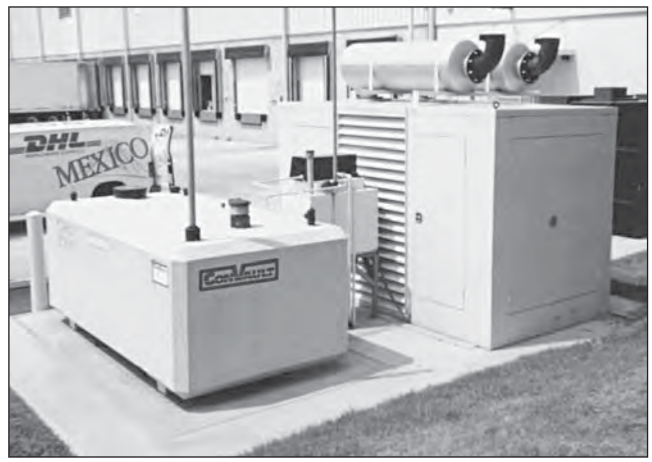


FIGURE 25.12 Aboveground storage tank and generator set. (Reprinted with permission of Core Engineered Solutions)

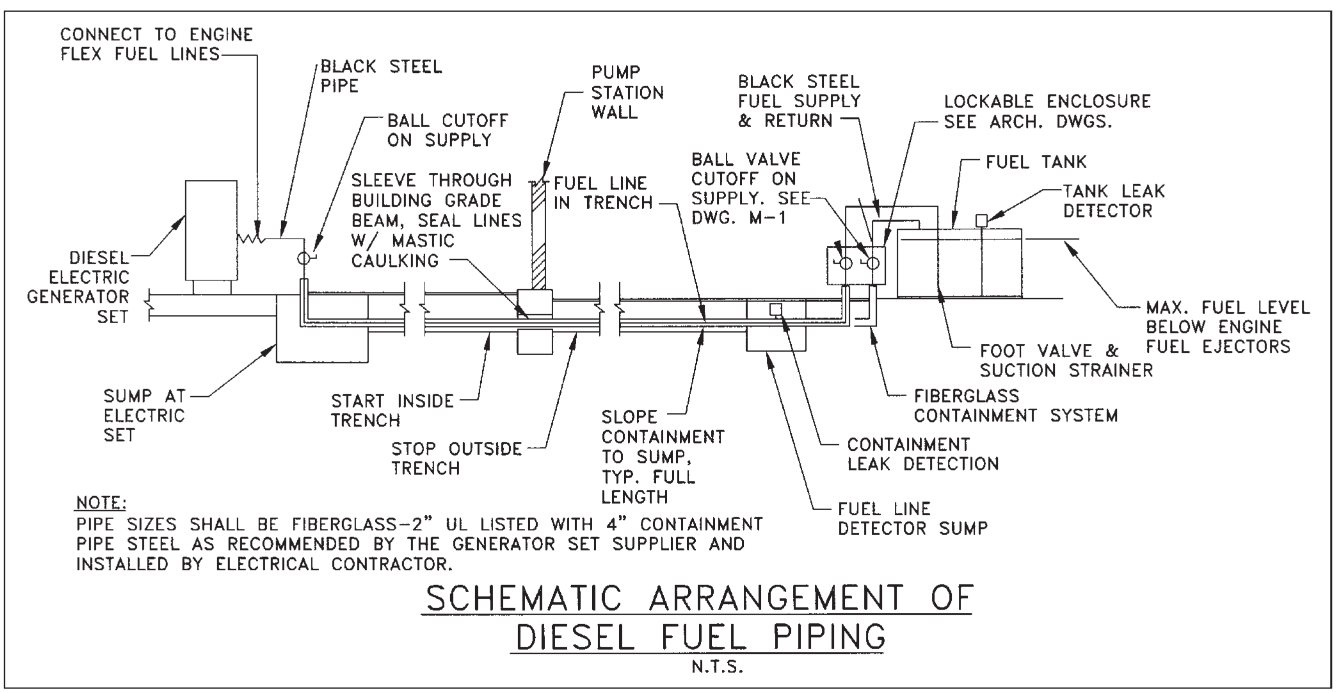


FIGURE 25.13 Schematic arrangement of diesel fuel piping.

designed to fit securely under a skid-mounted generator set. These tanks are double-walled for containment, and are protected by the generator shelter or enclosure and the skid framing. Their feed lines are inside the generator enclosure and are therefore also protected (see Figure 25.11).

Another option for an aboveground tank is a concrete-enclosed tank such as that provided by Convault (see Figure 25.12). The feed lines from the protected tank must also be protected. If buried, the lines need to be double-walled for containment. Some utilities also require the buried double-walled lines to be installed in a lined trench (see Figure 25.13).

SYSTEM COMPONENTS

Essential to a distribution system are such components as valves, fittings, fire hydrants, thrust blocks, service lines, and meters to control, direct, and measure the flow. The location and size of these components impacts the system's hydraulic efficiency and cost effectiveness as well as the health, safety, and welfare of the public.

Valves

Approximately 16.7 percent of all valves in use are for water and sewerage purposes (Merrick, 1991). In a waterworks system, valves are used to control flow directions, regulate flow rates, control pressure, isolate flows, and suppress transient waves. Typically, faucets, bibs, cocks, stoppers, and plugs are types of valves used in the water supply lines within a building, while gate valves, butterfly valves, and check valves are those typically used in water distribution lines serving the buildings.

A valve is completely closed when some type of operating mechanism, such as a wheel, forces the gasket or plug tightly against the fixed seat. The operating mechanism—that is, actuator—for a valve is either manual or automatic. Manual actuators include wheels and levers; automatic actuators can be electric, pneumatic, or hydraulic. Whereas automatic valves are more commonly used at the treatment facilities or pump stations, most valves used in the distribution pipe network are manual.

In addition to their function, valves are also described by their numerous characteristics such as size, material, fitting end, pressure rating, and actuator. The five most common types of valves used in waterlines are the ball valve, the plug valve, the gate valve, the butterfly valve, and the globe valve.

A *ball valve* (Figure 25.14) has a slotted spherical or section of a spherical closure element that rotates within the casing. The valve is opened when the opening is parallel to the flow direction. A ¼-turn of the opening closes the valve. Typically, ball valves are used for on-off service and throttling the flow.

A *plug valve* (Figure 25.15) is similar to the ball valve in that a cone or cylinder attached to a shaft, with a rectangular slot or circular orifice, opens and closes the flow by rotating the slot parallel to the direction of flow. Eccentric plug valves use a seat that consists of only part of the cone or cylinder to close the valve. The shaft rotates the seat over the pipe opening to regulate the rate of flow. Typically, plug valves are used for control and isolation purposes. Smaller plug valves are used on service connections and are referred to as service or corporation cocks. Plug valves have low head losses and typically cost more than gate, globe, and butterfly valves.

Gate valves, a type of the broader classification of slide valves, are the most frequently used when trying to isolate flows in the pipe network (see Figure 25.16). The gate valve (shutoff valve) is used to completely stop the flow through the pipeline. They operate by raising or lowering a plate or disc into the flow path. A shutoff valve's intended use is to operate in the full open or full closed positions only, and not as a throttling valve that is partially opened. Considerable wear and tear on the mechanism occurs in the partially opened position, and the head loss, at this position, is very high. Typically, gate valves are placed in valve boxes that extend to the ground surface to permit access. The valve is operated with an extension wrench that reaches down

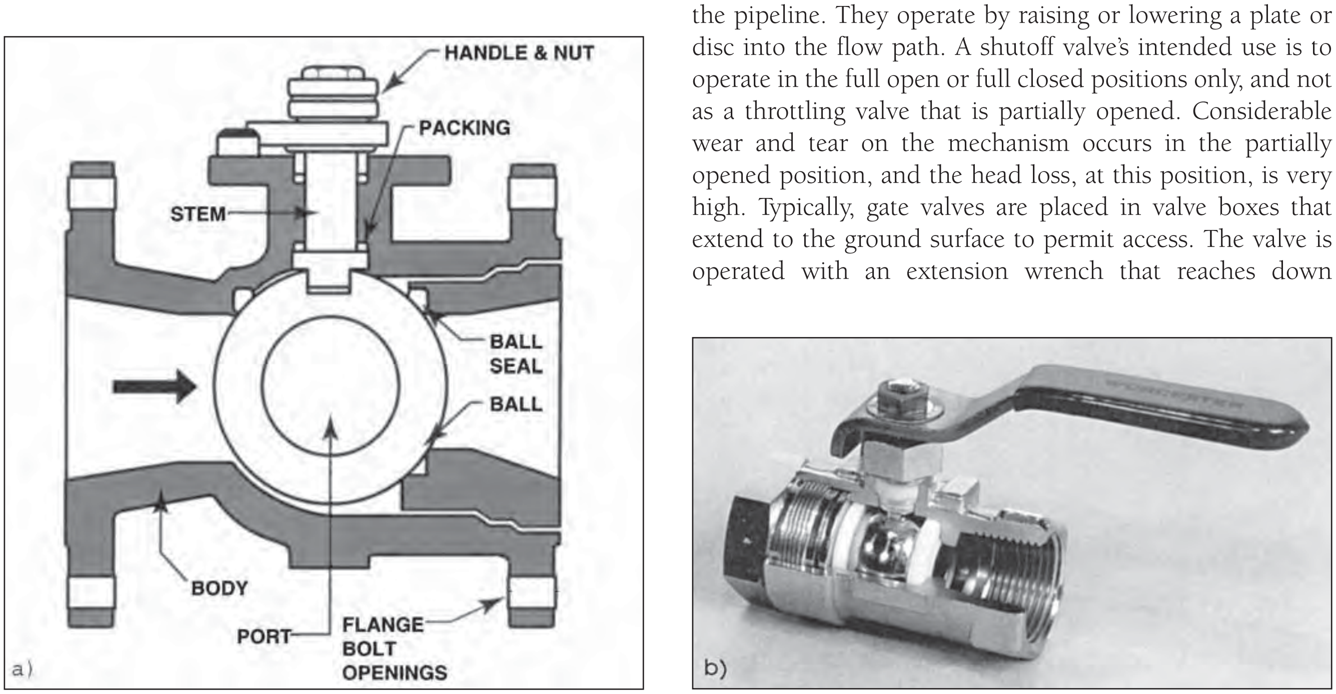


FIGURE 25.14 Ball valve: (*a*) schematic; (*b*) photo diagram. (Courtesy of Flowserve Corp.)

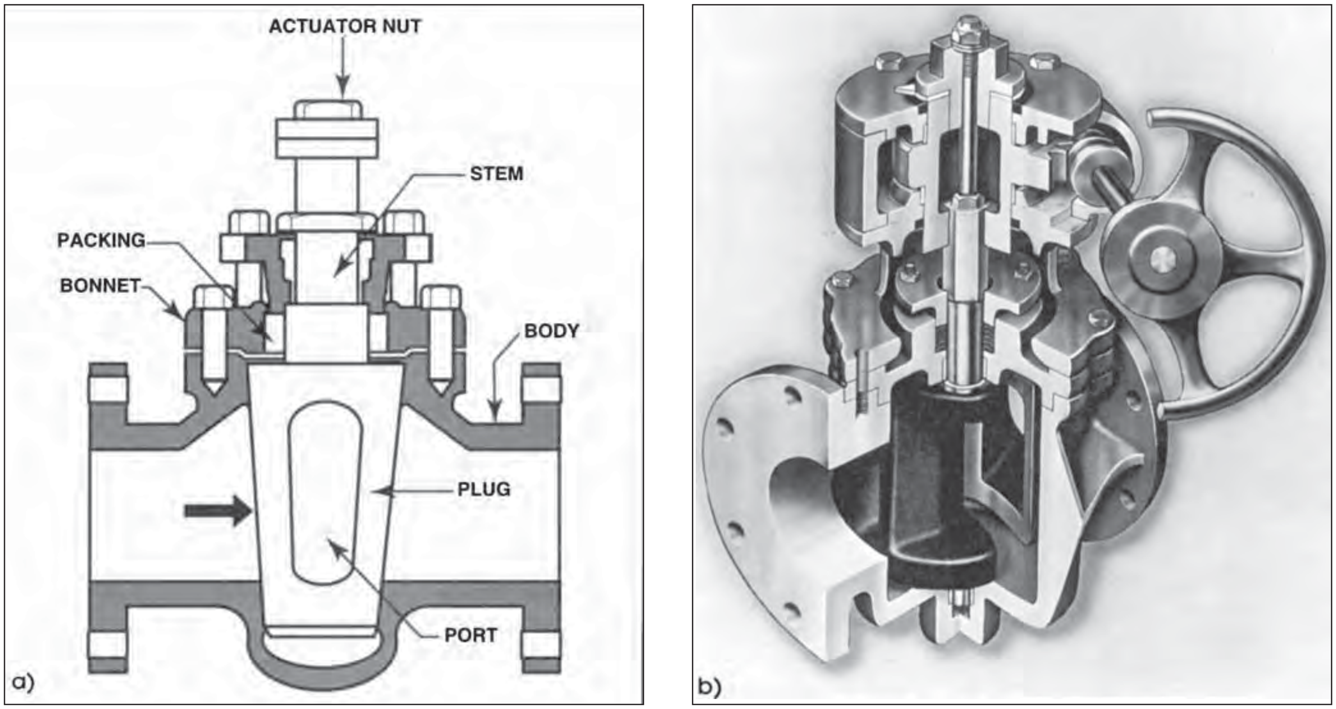
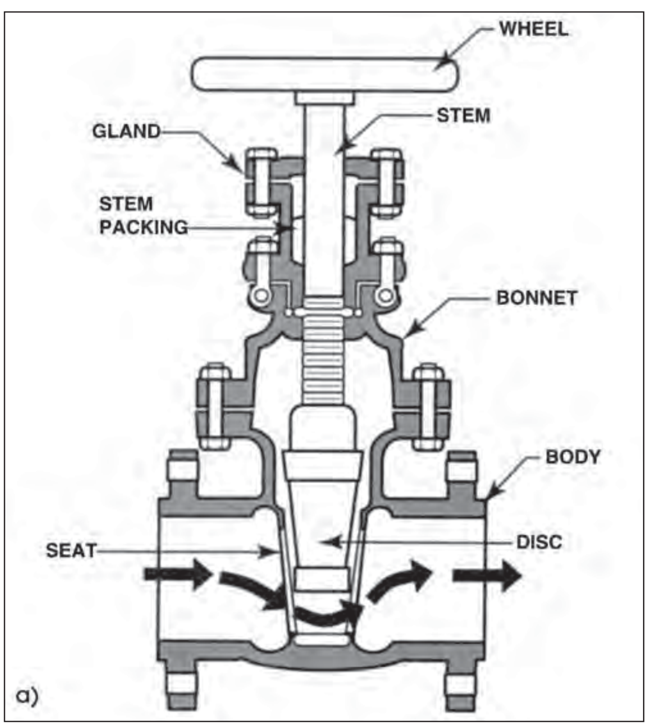


FIGURE 25.15 (*a*) Schematic diagram of a plug valve; (*b*) eccentric plug valve. (Reprinted with permission of DeZurik, Sartell, MN)

through the box to turn the operating nut on top of the valve stem.

As shown in Figure 25.17, a *butterfly valve,* also a type of rotary valve, consists of a thin disc that rotates about a thin shaft. When the face of the disc is parallel to the flow directions, the valve is fully opened. Butterfly valves can be used



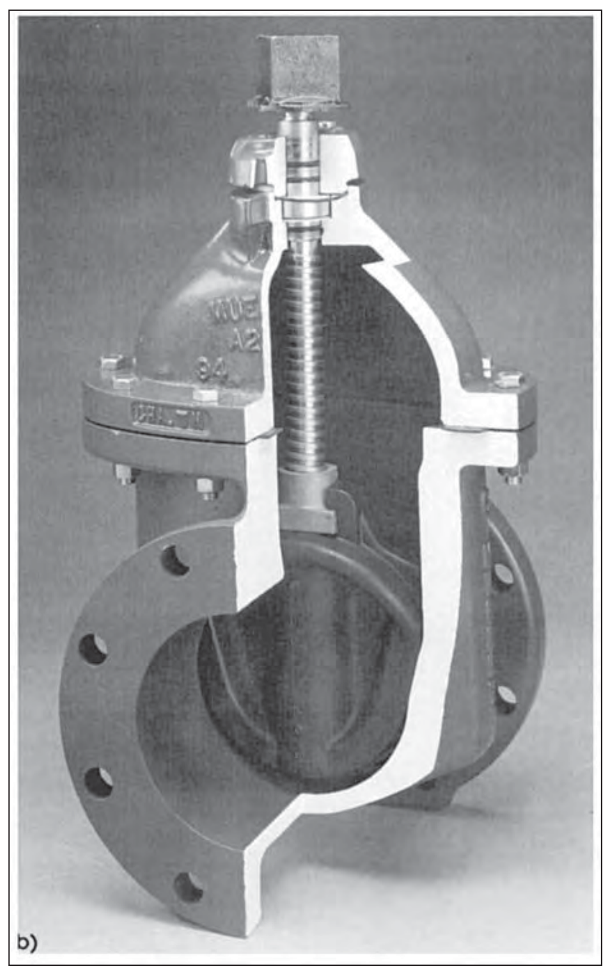
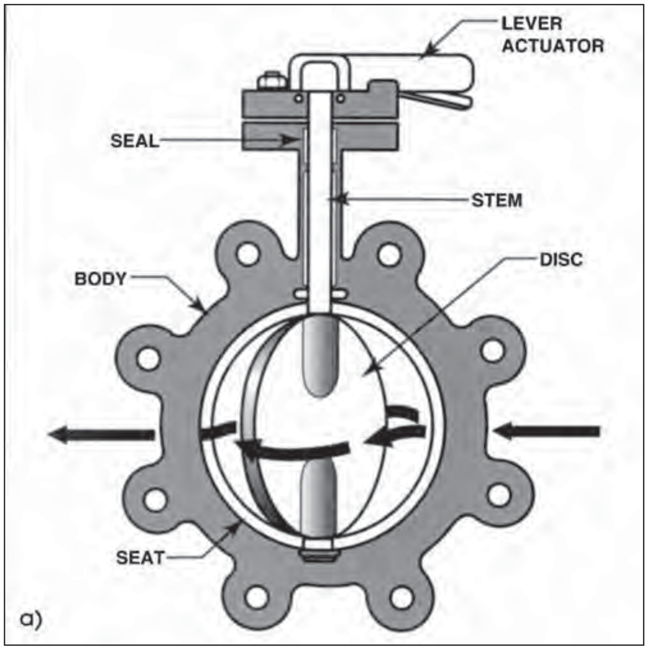


FIGURE 25.16 Gate valve: (*a*) schematic diagram; (*b*) resilient seat gate valve. (Reprinted with permission of Mueller Co., Decatur, IL)



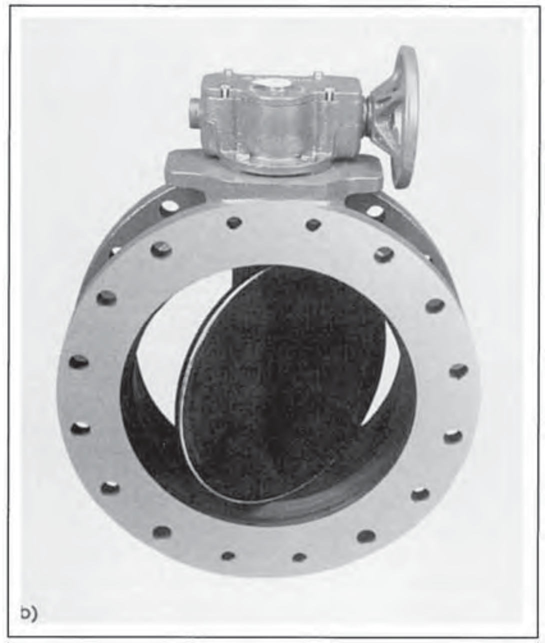


Figure 25.17 (*a*) Butterfly valve; (*b*) AWWA butterfly valve. (Reprinted with permission of DeZurik, Sartell, MN)

for either shutoff or throttling purposes. Although these types of valves have relatively low head loss, they present problems when cleaning since the disc is in the flow stream.

The *globe valve,* which is another type of slide valve, consists of a flexible disc attached to a screw-operated stem. A schematic diagram of a globe valve is shown in Figure 25.18. Raising and lowering the disc onto a horizontal seat controls the flow. Use of globe valves is most common in smaller domestic waterlines; a familiar globe valve is the household faucet. High-pressure losses are typical of most globe valves.

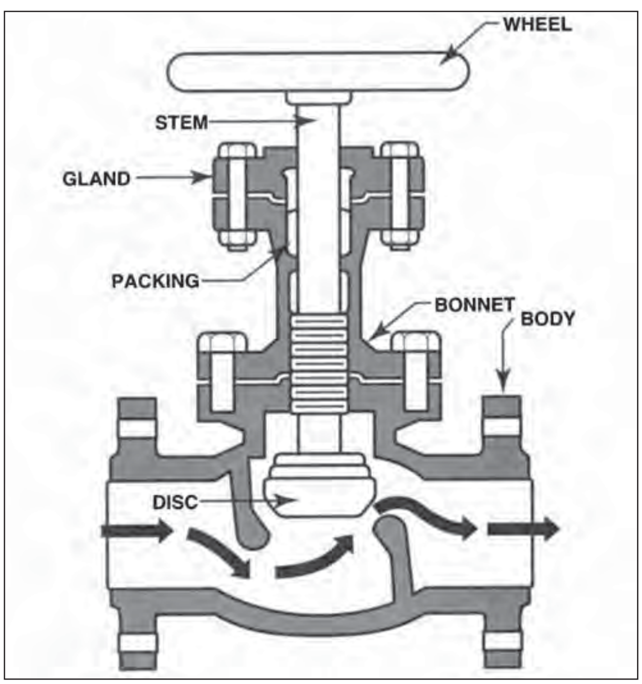


Figure 25.18 Schematic diagram of a globe valve.

A summary of the important characteristics of these particular valves appears in Table 25.9. In addition to the basic valves just described, there are other specialty valves used in waterworks systems.

Check valves are pressure-activated valves. Typical water main systems are bidirectional in that water flows according to the pressure differential in the pipes. Check valves are inserted to restrict flows to one direction. For example, a check valve on the discharge end of a pump or treatment plant prevents the water from reversing directions and flooding out the facility when the facility shuts down operation. Check valves are also used to control flows at the boundary of different water supply districts and service areas of different pressures.

Pressure-reducing valves (PRV) are automatic valves that protect against excess pressure in the waterlines. Pressure-reducing valves reduce pressure by controlling the flow and intentionally causing high head losses. Large pressure-reducing valves are operated by a smaller pilot valve. A wheel on the pilot valve sets the internal spring tension, which in turn sets the activating pressure. Larger PRVs are placed on lines between service areas of different elevations. Smaller PRV (less than 2-inch) valves are used to protect residential plumbing from excessive pressures in the main line. The valve acts as the transition between high-pressure zones and low-pressure zones. For example, if line pressures are greater than 70 lb/in^2, a pressure-regulating valve installed on a domestic service line reduces the service line to pressures so that the pressure will not damage household fixtures.

Altitude valves are automatically activated according to the pressure differential on either side of the seat. This type of

TABLE 25.9 Valve Summary (Water Distribution Operator Training HB, AWWA, 1976)

Valve Type	Common Size Range (in.)	Particularly Adapted to	Main Advantages	Main Disadvantages
Gate	½–24	Isolation services in distribution grids	Low cost in small sizes Low friction Good service life Ease of installation	High cost in large sizes Large sizes are quite heavy Poor for throttling; should not be used where frequent operation is necessary
Butterfly	3 & up	Isolation and automatic control	Low cost in larger sizes for normal service pressures Some types have very short lengths Ease of operation	Higher friction loss than gate valve Difficult to open in lines where differential pressures exist May cause problems when relining pipe Leaks because of seat damage
Globe	½–24	Isolation in smaller sizes Flow control in larger sizes Pressure control	Simple construction Dependable, can be used for throttling Good for pressure control Sediment or material unlikely to prevent complete closing	High friction loss Very heavy and expensive in large sizes
Ball and Plug	½–3 ½–12	Isolation and throttling	Dependable Very low friction loss Slow shut-off characteristic minimizes closing surges Ease of operation Resistant to erosion Long life	High cost in large sizes Very heavy

valve is usually used to control the flow to and from an elevated storage tank. The valve opens, allowing the tank to refill when the pressure in the distribution line is greater than the static pressure of the water in the tank. In times of high demand, when the pressure in the main decreases, the valve opens to allow the water in the storage tank to equalize the distribution system.

Blowoff valves and *drain valves* are used to dewater lines for repairs or remove accumulated sediment. These valves are most commonly used at the end of branches and at low points of the water main (see Figure 25.19).

Air-release valves. Water at standard conditions contains about 2 to 3 percent dissolved air by volume. The amount of dissolved air in a waterline system is governed by the turbulence before it enters the system and the pressure and temperature within the system. Pressurized distribution systems change elevations as the pipe follows the terrain. In effect, the changes in elevation change the pressure in the system. Consequently, the air dissociates from the water and collects at the higher points in the pipeline. Since the return of air back into the water does not occur as readily as it leaves the water, air pockets form and add 10 to 15 percent more resistance to the flow. Additionally, these pockets can lead to air lock of the system, which can completely stop the flow. Typically, air-release valves are installed at the local peaks in the pipe system. As shown in Figure 25.20, a peak is any section of pipe that slopes up toward the hydraulic grade line or runs parallel to it. Air-release valves should also be considered in sections where there is an increase in the downward slope or decrease in the upward slope[1] of the pipe.

Hydraulic surge (water hammer) can occur when water flowing in a long pipeline suddenly stops. Surge can actu-

[1]Golden Anderson Automatic Valve Reference Manual, Golden Anderson Industries, Inc., PA.

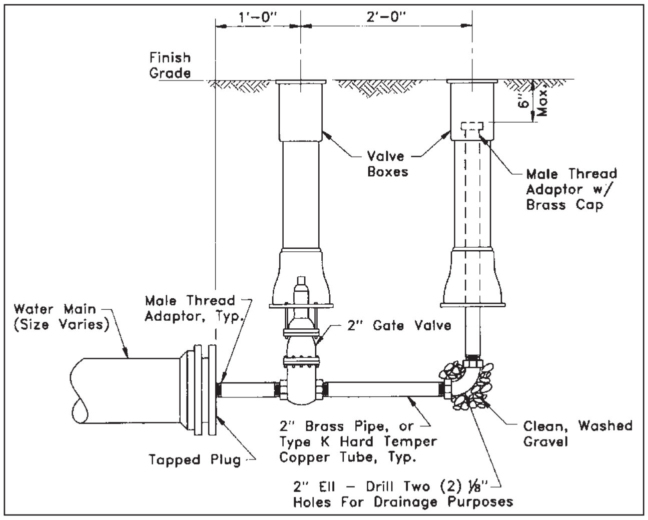


Figure 25.19 Two-inch blowoff valve detail.

ally cause a water column separation at high points, or peaks, on the main. This, at first, exerts a tremendous negative pressure (or vacuum) on the main that can cause it to collapse. If the system does not collapse, the vacuum will be followed immediately by a pressure spike that can rupture the pipe as the separated water columns reunite. To prevent this, a combination of air-release and vacuum relief valves are used at points on water mains where analysis indicates water column separation might occur. The vacuum relief valve lets air into the pipeline during hydraulic surge to both relieve the vacuum and provide a volume of air that cushions the pressure spike caused by the two water columns coming together again. Note that hydraulic surge analysis is a specialized field and must be done by qualified personnel.

Pipes, Joints, and Fittings

Typically, pipes used in waterworks systems are classified according to their design working pressures. The four most common classes of working pressures are 100, 150, 200, and 250 lb/in^2. Other parameters for identifying pipe strength are the bursting strength rating, which identifies the strength against internal forces caused by hydrostatic and hydrodynamic pressures such as pressure surges and water hammer, and the crushing strength, which deals with the external forces related to soil, vehicles, and impact loadings.

Typical standard pipe diameters used in distribution systems range from 6 inches through 20 inches in 2-inch increments. Then, beginning with 24 inches, diameters increase in 6-inch increments. For residential plumbing pipe, diameters begin at ½ inch and increase in ¼-inch increments. Since manufacturers and pipe material dictate the available pipe diameters, diameters other than those mentioned here might be available. The supplier should be contacted to verify the pipe diameters that are available and whether they are in stock.

Although ductile iron pipe is the most popular cast-iron pipe, other common pipe materials for water distribution lines include gray cast iron, steel, plastic, and polyethylene. Note that this same type of piping is used for water service lines larger than 2 inches. Copper or plastic tubing is commonly used for service lines smaller than 2 inches.

Plastic Pipe. Distribution lines for small water systems are normally constructed of PVC pipe because of its ease of construction and economy. Plastic pipe used for drinking applications should be certified by an acceptable testing laboratory (such as the National Sanitation Foundation) as nontoxic and not producing objectionable taste. Standards for PVC pipe (up to 12 inches) for underground service are ASTM D1785, ASTM D2241, and ANSI/AWWA C900. ASTM D1785 pipe is available in Schedule 40, 80, and 120 thickness. ASTM D2241 pipe has pressure ratings up to 250 lb/in^2, while AWWA C900 pipe is available in pressure ratings up to 200 lb/in^2. AWWA C900 pipe is manufactured to ductile-iron pipe outside dimensions, and both ASTM D2241 and ASTM D1785 are manufactured to steel pipe outside dimensions. Joining these pipes requires a transition gasket used with standard ductile-iron fittings.

Ductile-Iron Pipe (DIP). DIP is standardized in ANSI/AWWA C150/A21.50-96, and is available in sizes from 3 to 64 inches in various pressure classes. Push-on or mechanical joints are used on DIP for underground service. For water service, DIP is normally lined with cement-mortar. Soft water will leach the cement-mortar lining if not properly conditioned. Depending on soil conditions, DIP is often installed in polyethylene wrapping to aid in corrosion protection.

Steel Pipe. Steel pipe is normally used for large-diameter installations beyond the sizes of which DIP is available and is not often used for small water systems. However, it is available in various sizes and thickness classes. It is covered under AWWA C200 standard. Note that buried steel pipe is more susceptible to corrosion than DIP and must be adequately protected. It is usually installed underground with a tape-wrap coating as a minimum, and the pipe interior is normally specified to be provided with a cement mortar lining for drinking water service.

Polyethylene Pipe (PE). PE is becoming popular for small water service, mainly because it is economical to purchase and install. PE is available in sizes larger than 4 inches and the standard for PE is AWWA C906.

High-Density Polyethylene Pipe (HDPE). HDPE is popular in directional drilling applications. The pipe is fused together with a machine that provides a jointless connection. The pipe is flexible and can be installed around a radius without the use of joints. The pipe is covered under ASTM D1248, ASTM 3350, AWWA C901, AWWA C906, and NSF Standards 14 and 61. It can be used in a direct burial application or with a directional drilling machine that bores a hole through the ground for a specified distance and then pulls the pipe back into the void. The directional drilling application can be used to install the pipe in numerous situations such as under environmentally sensitive areas, railroad rights-of-way, and road rights-of-way.

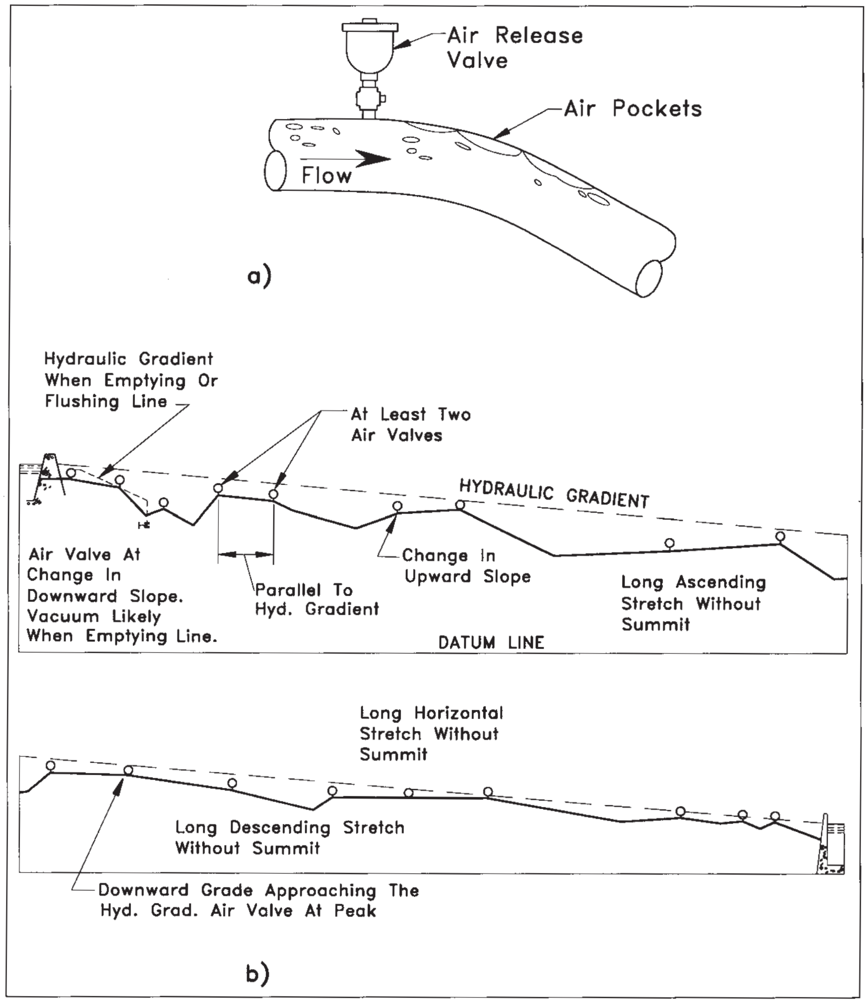


FIGURE 25.20 (*a*) Typical bubble behavior; (*b*) suggested air-release valve locations. (Reprinted with permission of GA Industries, Inc., Cranberry Township, PA)

Additionally, it is important to note that ductile-iron pipe (DIP) and prestressed concrete cylinder pipe (PCCP) are typically used for larger-diameter waterlines such as transmission lines from treatment facilities to the distribution network.

Joints. Distribution pipes are connected by either of the several different types of joints shown in Figure 25.21.

The *push-on joint* is a compression joint that creates a pressure-tight seal when a gasket inside the bell end is compressed by the plain end of the pipe. This type of joint allows for fast and easy installation and is low in cost, which probably accounts for its popularity. However, this type of joint does not restrain the individual lengths of piping from separating under pressure, so concrete thrust blocks are cast at elbows and other turns to restrain the pipe. Soil friction on the pipe also acts to prevent joint separation. The push-on joint is not suitable for aboveground use in pressure piping.

For the *mechanical joint,* the pipes fit together as a plain end inside a bell-shaped end. A pressure-tight seal is created by a gasket tightened between the flange on the bell end and the gland, a flangelike collar that slips over the plain end. The flange and gland are held together with bolts. The mechanical joint is considered a semirestrained joint because friction in the highly compressed gasket provides some restraint against pipe separation under pressure. Where joint restraint is not provided by thrust blocking, as for the push-on joint, a restraining collar with locking bolts is used to hold the joint together. The mechanical joint is easy to assemble and is intermediate in cost between the push-on joint and the more costly ball joint, flanged joint, or threaded joint.

The *ball joint* is used for crossing waterways, as a restrained joint, and where free-turning deflections are needed. The gasket is inserted into the bell and compressed by the entering ball. The joint is secured by locking the bayonet-type retainer over the lugs on the bell. A retainer lock inserted between the lugs prevents the retainer from rotating.

The *flanged joint* is used for the larger sizes of aboveground distribution piping, such as in pump stations. This joint is seldom used for underground distribution piping because of its cost and difficulty of installation. The flanged joint has a flat-faced or flat-faced with gasket groove bolt collar or flange on each end of the pipe. A suitable gasket is placed between the flange faces and compressed by the bolts to form a pressure-tight joint. The flange joint is the strongest of the joints. The chief disadvantage of the flange

FIGURE 25.21 Joint connections for cast-iron pipe. (Reprinted with permission of McWane Cast Iron Pipe Company, Birmingham, AL)

joint is that usually some type of length-compensating joint must be included in the pipe run because, as the flange bolts are drawn up, the overall length of the pipe run is shortened by the compression of the gaskets.

The *threaded or screwed joint* is formed by cutting threads into the end of the pipe on a tapered diameter, in other words, pipe threads. When the tapered threads are screwed together, they create an interference fit, which makes a pressure tight joint with the aid of a mastic pipe sealing compound on the threads. The threaded joint is not commonly used for distribution piping, since it is difficult to make in larger pipe sizes, and, due to the loss of metal in the pipe wall at the threads, it is weaker than the flanged joint.

The ball, flanged, and threaded joints are considered restrained joints because they will hold the individual lengths of pipe together under system operating pressure and are, therefore, suitable for aboveground use.

Fittings. Fittings are used to connect same- or different-size pipes, change the flow direction, split the flow into several directions, and stop the flow. Examples of fittings commonly used in the distribution network are crosses, tees, wyes, and bends. Standard bends are 90° or full bends, 45° or ½° bends, 22½° or ¼° bends, and 11¼° or ⅛° bends. Fittings are readily available in standard sizes. Nonstandard sizes are special-order items from a manufacturer. Because the special-order items cost significantly more and may delay construction while on order, their use and necessity in design should be avoided except in the most extreme cases. Typically, the AWWA, ANSI, and ASTM designate acceptable standards and specifications for various pipes and fixtures for supply water systems. Examples of various fittings are shown in Figure 25.22.

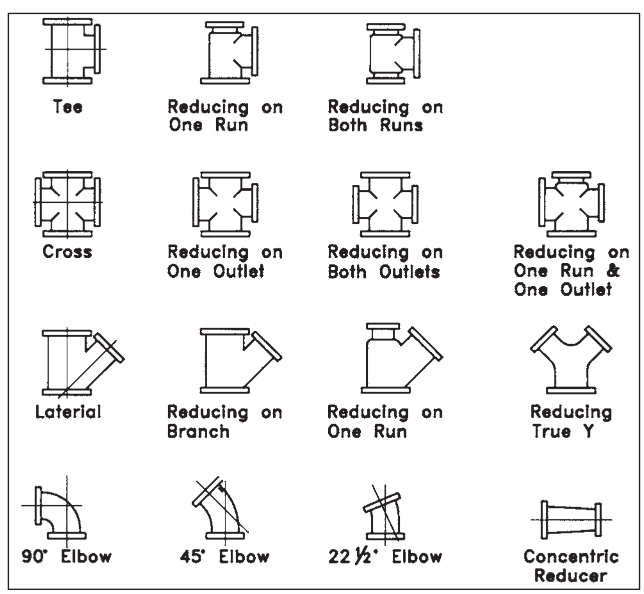


FIGURE 25.22 Various types of fittings.

Fire Hydrants

A fire hydrant consists of the aboveground barrel that extends below grade to the water supply line. The supply line connecting the barrel to the water main is a minimum 6-inch-diameter pipe. Typically, a gate valve located in an underground valve box allows for shutoff and repair. Maximum recommended friction losses are 2.5 lb/in^2 in the hydrant and 5 lb/in^2 in the water supply line, from the main to the hydrant, for flows of 600 gpm. Hydrants have various nozzle arrangements, but the most common hydrant has two 2.5-inch hose connections and one 4.5-inch pumper connection. The bend directly below the barrel connects the barrel to the supply line. A thrust block prevents movement from lateral forces and a concrete block underneath the bend prevents excessive settling. After use of the hydrant, the barrel is drained by way of a drain near the base of the barrel. A gravel bed surrounds the thrust block or bend to allow for draining of the barrel.

Meters

Meters are commonly used for measuring water for setting cost, collecting payments from customers, and determining fair distribution of water delivery costs. Other uses for meters include measuring flow to and from treatment plants and reservoirs, blending water and chemicals, and measuring water sold to other jurisdictions.

Meters used to measure usage for residential dwellings and commercial use are located in areas easily accessible to the water utility company. They should not interfere with public safety nor act as a hazardous obstacle. Most meters are located below ground surface levels for safety and to reduce damage due to weather and tampering. Occasionally, meters will be located inside the building with a remote recorder mounted on the outside.

Meters are available in the same sizes as pipe diameters. Usually the meter is sized one diameter size less than the pipe for reasons associated with accuracy, head loss, and cost. Unlike pipe, where the cost differential between successive pipe sizes may be on the order of 10 percent to 25 percent, the cost differential between successive meter sizes can be significantly more. Downsizing the meter also downsizes succeeding appurtenances and fixtures, thereby reducing costs. The increase in accuracy in using the smaller-size meter is counterbalanced by an increase in the head loss. Usually the cost savings and the accuracy offset the drawback incurred from the increased head loss.

Thrust Restraint

Two basic forces associated with flowing water under pressure are the hydrostatic forces and hydrodynamic forces. Simply explained, hydrostatic forces are due to the pressure exerted by a depth of fluid, as shown in Figure 25.23. This pressure force acts perpendicular to a surface. Thus, for a pipe with full flow, the pressure acts radially outward and also along the longitudinal axis of the pipe.

Consider a pipe connected to a tank and plugged at the other end, as shown in Figure 25.23. From basic hydrostatics, the pressure on the plugged end of the pipe is propor-

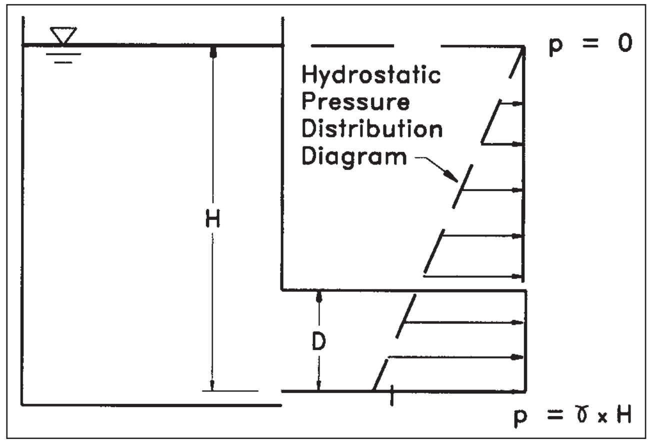


FIGURE 25.23 Hydrostatic pressure in a pipe.

tional to the depth of water *H,* as shown by the hydrostatic pressure distribution diagram. The pressure, *p,* is equal to γH, where γ is the specific weight of the fluid. The magnitude of the force acting at the end of the pipe is equal to the product of the pressure and the cross-sectional area of the pipe $F_p = \gamma HA$, where *A* is the cross-sectional area of the pipe.

Hydrodynamic forces are the result of changes in momentum of the moving fluid. Any change in direction or magnitude of flow velocity results in a change in momentum of fluid. Fittings such as bends, tees, and wyes change the direction of flow; nozzles, valves, and reducers change the cross-sectional area of the flow path. Each of these fixtures has force acting on it due to hydrostatics and hydrodynamics.

The impulse-momentum equation (assuming incompressible flow) determines the resultant hydrodynamic force of the water on the fitting. The impulse-momentum equation, in vector component form, is:

$$\sum F_x = \rho Q (\Delta V_x) \tag{25.5}$$

$$\sum F_y = \rho Q (\Delta V_y)$$

where *Q* is the discharge, ρ is the density, and V_x and V_y represent the *x* and *y* components of velocity. Consider the horizontal bend of Figure 25.24*a.* The force of the water on the bend is the result of the pressure forces *pA* acting on the water within the bend, as illustrated in Figure 25.24*b.* To counter these forces, an equal and opposite force is produced by the longitudinal stresses in the pipe wall (Figure 25.24). Since common pipe joints cannot resist these longitudinal forces, the developed forces must be reduced or eliminated by additional anchors, either in the form of thrust blocks or with supplemental clamps and collars at the joints.

As an example of the magnitude of such forces, consider a typical water distribution pipe system. Typically, the operating pressure ranges from 40 to 150 lb/in^2 with velocities approximately 3 to 10 fps. Within these ranges, hydrostatic forces are far greater than hydrodynamic forces and, for the purposes of design, can be ignored in most cases. To illustrate this point, consider a 12-inch diameter, 45° horizontal bend. Assume line pressure of 50 lb/in^2 and flow velocity of

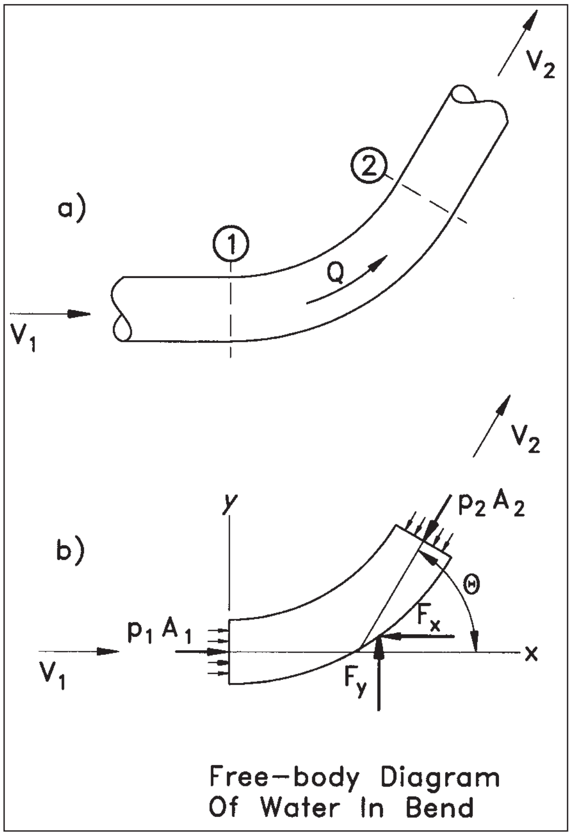


FIGURE 25.24 Forces for flow through a horizontal bend.

5 fps. The right side of the momentum equation (Equation 25.5) is the force due to the change in momentum of the fluid. The left side represents all forces acting on the fluid such as gravity, pressure forces, and shear forces. For the conditions given, let F_x and F_y represent the forces of the bend on the fluid. Expanding Equation 25.5 gives:

$$p_1A_1 - F_x - p_2A_2\cos 45° = \rho Q(V_2\cos 45° - V_1) \qquad (25.6)$$

$$F_y - p_2A_2\sin 45° = \rho QV_2\sin 45°$$

Rearranging terms and substituting the appropriate values,

$$\left(50\text{ psi} * 144\,\frac{\text{in}^2}{\text{psi}}\right)(0.79\text{ ft}^2) \qquad (25.7)$$

$$-\left(50\text{ psi} * 144\,\frac{\text{in}^2}{\text{psi}}\right)(0.79\text{ ft}^2)\cos 45°$$

$$-\,1.94\text{ slugs} * 3.9\,\frac{\text{ft}^3}{\text{sec}}$$

$$\times\left(5\,\frac{\text{ft}}{\text{sec}}\cos 45° - 5\,\frac{\text{ft}}{\text{sec}}\right) = F_x$$

or

$$1666\text{ lbs} - (-11\text{ lbs}) = 1677\text{ lbs} = F_x \qquad (25.8)$$

Similarly the y-component of the force is:

$$\left(50\,\frac{\text{lbs}}{\text{in}^2} * 144\,\frac{\text{in}^2}{\text{ft}^2} * 0.79\text{ ft}^2\sin 45°\right) \qquad (25.9)$$

$$+\,(19.4\text{ slugs}) * \left(3.9\,\frac{\text{ft}^3}{\text{sec}}\sin 45°\right) = F_y$$

or

$$5688\text{ lbs} + 5.4\text{ lbs} = 5693\text{ lbs} = F_y \qquad (25.10)$$

The preceding computations show that, for conditions typical of water distribution systems, the components of the momentum force (i.e., 11 lb and 5.4 lb) are substantially less than the x and y components of the pressure forces, namely 1666 lb and 5688 lb, respectively.

The types of joints commonly used to connect ductile-iron pipes are push-on or mechanical joints. Although leakproof and quite effective for normal radial stresses, these joints are not capable of resisting the hydrostatic and hydrodynamic forces at the components in the longitudinal direction. Added measures are necessary to reinforce longitudinal separation at the joints. Thrust blocks are used to transfer the fluid pressure forces to undisturbed soil. Other measures include collars and clamps around the joints to provide additional restraint.

The design concept of thrust blocks is similar to foundation design. The intent is to transfer internal hydrostatic forces to the undisturbed soil mass through a mass of concrete. For a given hydraulic design, the size of the thrust block depends on the bearing capacity of the soil and the hydrostatic forces within the waterline component. Figure 25.25 shows the magnitude and line of action of hydrostatic forces for various types of waterline components. The location of the thrust block depends on the type of pipe fittings. Parameters considered in the design of thrust blocks include pipe size, hydrostatic pressures, type of component, and soil properties.

The Ductile Iron Pipe Research Association (DIPRA) recommends the schematic shown in Figure 25.26 for thrust block design.

Bearing surface of the block should be placed against undisturbed soil. Alternatively, when this is not possible, the fill soil between the block and the undisturbed earth must be compacted to minimum 90 percent Standard Proctor density. The required bearing block area is

$$A_b = hb = \frac{TS_f}{S_B} \qquad (25.11)$$

where:
A_b = the bearing surface area of the block
h = height of the block
b = width of the block
T = the resultant hydrostatic thrust force on the component. The hydrostatic forces (PA terms) corresponding to T are found from Figure 25.25.
S_f = factor of safety (usually 1.5 for thrust block design)
S_B = bearing strength of the soil (psf)

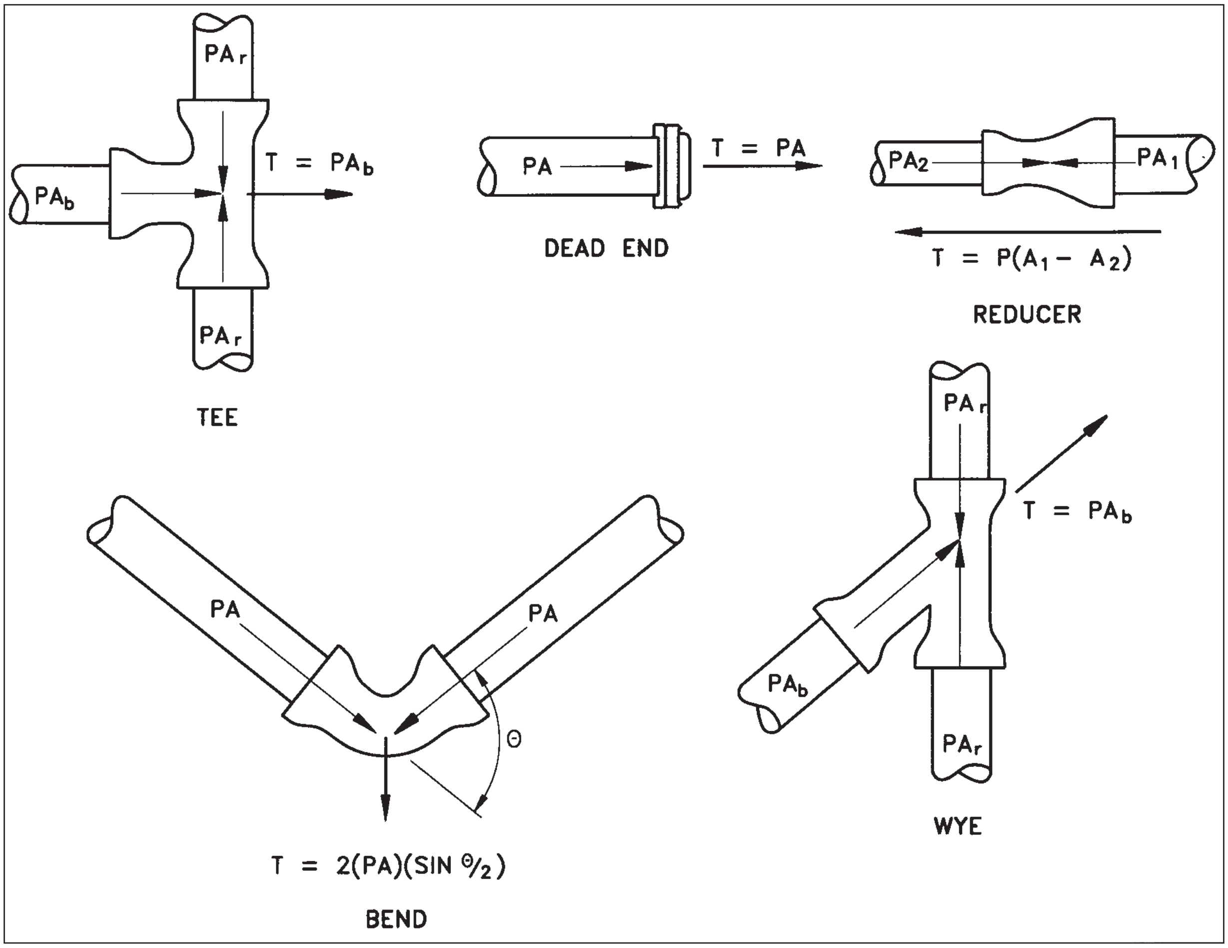


FIGURE 25.25 Thrust forces and line of action for selected fittings. (Reprinted with permission of Ductile Iron Pipe Research Association, Birmingham, AL)

The block height h should be equal to or less than one-half the total depth to the bottom of the block H_T, but not less than the pipe diameter D.

Block height h should be chosen such that the calculated block width b varies between one and two times the height.

Table 25.10 provides bearing strengths for generalized soil that can be used whenever actual bearing strengths are not available. The engineer is responsible for proper selection of the bearing strength based on proper soil identification. The DIPRA suggests that, in lieu of the values for soil-bearing strength shown in Table 25.10, a designer may choose to use calculated Rankine passive pressure or other determination of soil-bearing strength based on actual soil properties.

On horizontal bends, the placement of the thrust block is against the outer edge of the bend. On vertical down bends, similar placement would put the thrust block on top of the pipe. Besides the danger of crushing the pipe, the fill dirt on top of the block would provide marginal bearing support. Instead, the vertical down bend is stabilized with a gravity thrust block attached to the underside of the bend (see Figure 25.21b). The vertical component ($T_y = PA \sin \theta$) of the thrust force is countered by the weight of the block itself. The required volume of the block is

$$V_G = \frac{S_f PA\,(\sin \theta)}{W_M} \tag{25.12}$$

where V_G = the volume of the block and W_M = density of the block material. The horizontal component of the thrust force $T_X = PA\ (1 - \cos \Theta)$ is transferred to the soil by the right side–bearing area of the block.

In situations where thrust blocks cannot be used, another common method for thrust resistance is the use of restrained joints. A restrained joint is a specially designed joint that provides longitudinal restraint. The thrust force at the component is transferred to the surrounding soil through frictional resistance and bearing from a predetermined length of pipe.

Other types of thrust resistance include steel straps attached to boulders and bedrock (not very common), and tie rods connecting collars on either side of a joint.

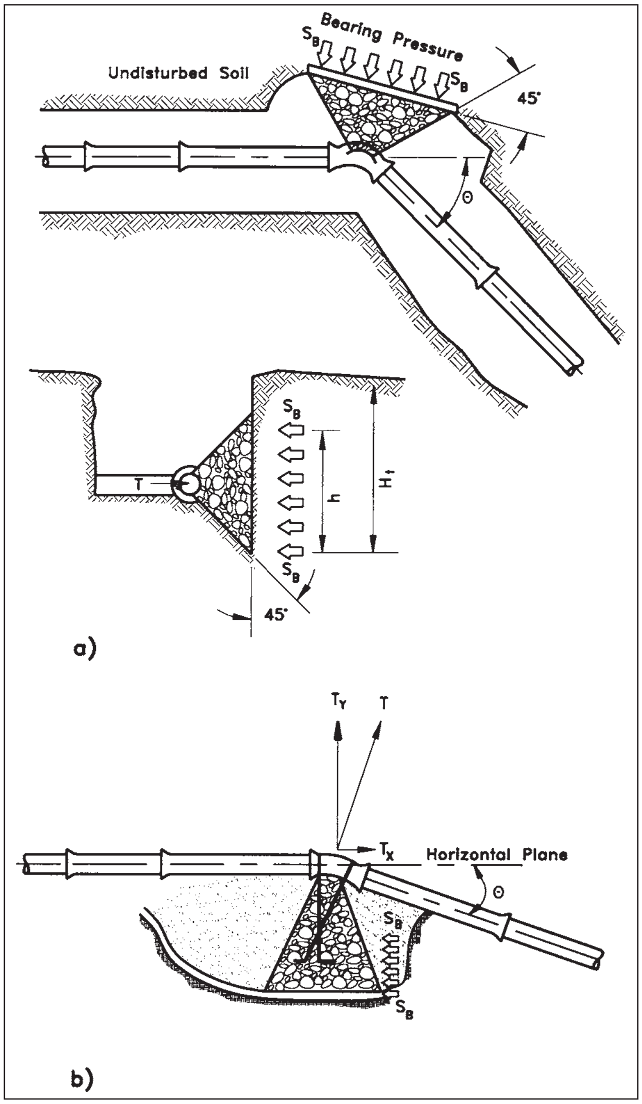


Figure 25.26 Schematic for (*a*) bearing block; (*b*) gravity block. (Reprinted with permission of Ductile Iron Pipe Research Association, Birmingham, AL)

TABLE 25.10 Bearing Strength of Generalized Soils

Soil	Strength (S_B)* (lb/ft^2)
Muck	0
Soft clay	1000
Silt	1500
Sandy silt	3000
Sand	4000
Sandy clay	6000
Hard clay	9000

*Although the above bearing strength values have been used successfully in the design of thrust blocks and are considered to be conservative, their accuracy is totally dependent on accurate soil identification and evaluation. The ultimate responsibility for selecting the proper bearing strength of a particular soil type must rest with the design engineer.
(Reprinted with permission of Ductile Iron Pipe Research Association, Birmingham, Alabama.)

SYSTEM LAYOUT CONSIDERATIONS

Pipe Network

In residential areas, distribution lines typically follow the street network and are usually located within the public right-of-way. Some localities require the location of the waterline to be a fixed distance from the centerline, curb line, or right-of-way line and on the same side of the street for uniformity. For instance, in some parts of the United States, the waterline is laid on the north and east side of the centerline. Whether the water main is located under the pavement or behind the curb line is a matter of preference set by the local standards.

Although the grid layout is preferable to the branching layout, dead-end lines cannot always be avoided. Therefore, most distribution systems are a combination of loops and branches with the branch lines kept to a minimum. Many branch lines are temporary and are built for the convenience of future connections needed when new developments are added and streets are extended. Cul-de-sac streets, common in residential developments, make looping of distribution lines difficult since easements are required to extend the waterline through private property. The water supply company, in its desire to minimize dead-end waterlines, may require the developer to provide easements through the project for interconnecting the waterline. The easements should preferably run through outparcels and common land rather than individual lots. However, if the waterline must pass through a lot, the preferred location is along lot lines, with the lot lines coincident with the edge of the easement. Note that this method of locating the easement must comply with other subdivision and zoning constraints; for example, the waterline must meet the criteria for minimum distance to dwellings and other structures.

Location of water mains in commercial areas and high-density residential areas (e.g., town houses and condominiums) is dictated, in part, by other utilities, their structures, location of fire prevention and control devices for the internal parts of the building (e.g., fire hose connections, sprinkler systems), location of fire hydrants, and type of metering system. Generally, these sites contain a more complex maze of underground utilities within the travelways, and this complexity presents obstacles in the layout. To illustrate, the travelways are narrower than public street rights-of-way; the sites contain higher impervious areas, which translates to more storm sewer pipe and inlets; and the higher density usually means more sanitary connections. Since waterlines are normally nongravity dependent, the waterline can be adapted to weave over, under, and around the other gravity-dependent utilities.

Although water mains are usually no smaller than 6 inches in diameter, 4-inch lines may be acceptable for special situations such as stub lines serving fire hydrants and lines that serve only a few residential units. Typical pipe sizes for water mains are 4-, 6-, 8-, 12-, 16-, 18-, and 24-inch diameters. The size varies according to the specifications of the jurisdiction and the availability of pipe materials. Since the velocity increases as the diameter decreases, smaller-diameter pipes result in higher head losses for the same discharge. Velocities of 3 fps to 6 fps at normal working conditions are preferred, although higher velocities in short lengths of pipe for short periods are tolerable. Note sustained high-discharge velocities scour the interior of pipes.

For health safety reasons the horizontal distance between a waterline and a sanitary sewer line or manhole should be a minimum of 10 feet. Pipes and pipe joints may develop leaks due to deterioration, improper construction, and excessive pressures. Contamination of the water supply from the sanitary wastewater system presents a potential for creating a major health problem as well as a major cost in locating the point of contamination and repairing it. When the water and sanitary sewer line are essentially parallel and the horizontal distance is less than 10 feet, special provisions are made to ensure no contamination. When the water main is in the vicinity of a sanitary sewer, the water main should be above the sanitary line with a minimum distance of 18 inches between the invert of the waterline and the crown of the sanitary pipe. In addition, pressure pipes should be used for the sanitary sewer with watertight joints to provide additional protection from contamination. Sanitary sewer manholes in the vicinity of water mains must also be of watertight construction. As an alternative, design standards may require concrete encasement of the waterline when it falls in close proximity to sanitary lines. In the extreme cases, when the sanitary line must be above the water main, the sanitary sewer should have adequate support (e.g., concrete cradle) to prevent excessive deflection, settling on, and breaking the waterline. If the sanitary sewer crosses the water main, not only are the upgraded materials used, but the water main section of pipe should be centered at the point of crossing to put the water main's pipe joints as far from the sanitary pipe as possible.

Waterlines are set at a depth below the frost line. The engineer profiles the waterline after the horizontal layout is complete to show how the waterline weaves over and under other utilities in the development. Minimum clearance between water main and storm sewer is approximately 1 foot. When the water main passes under a storm sewer pipe, additional structural support to the storm pipe should be considered to prevent crushing of the water main. When water mains pass over utilities at less than minimum depth, consideration for freezing is necessary.

Waterlines can also be installed using directional drilling machines that facilitate "trenchless" installation. This type of installation is beneficial in several different scenarios. For example, when the waterline must be extended across waterways such as streams to serve another section of the distribution system, a directional drilling machine allows the line to be installed without impacting the stream or other environmentally sensitive areas such as wetlands. A directional drilling machine can also be used to extend a water distribution line across a congested roadway in a manner that avoids significant disturbance to everyday vehicular traffic that occurs with typical open trench excavation.

Valve Locations

Isolation valves are placed on the line for shutting down a section of the system for repairs and maintenance. Recommended valve spacing ranges from 500- to 1200-foot intervals. Since the purpose of isolation valves is to shut down a section for repairs, the objective in placing the valves is to balance the economics of using as few valves as possible with the inconvenience of the smallest number of customers when a section is shut down.

Most water main systems follow a community's public road. In moderate- to high-density (i.e., more than three du/ac) residential and commercial areas, the frequency of street intersections is typically less than 1000 feet and in many developments 500 feet and less. At these intersections, tees and crosses divide the waterline into other feeder lines. Included with these tees and crosses are valves that allow for various ways to segment small service areas. Generally, valves are placed on two sides of a tee and three sides of a cross. At the tees, one valve is placed on the minor line. Likewise, with crosses, valves are placed at each side of the minor connection (see Figure 25.27*a*). The location of the remaining valves for the cross and tee depends on the location of the valves at the next junction upstream and downstream from the point under consideration. Referring to Figure 25.27*a,* recognize that two valves at each tee can accomplish the same results as three valves. The water main segments of B-D, D-F, and C-E can be isolated without the need for a valve at P.

The exception to the rule occurs on tees where the stub side connects to either a reasonably large commercial building or a fire hydrant. In these cases, valves are placed on all three sides of the tee, as shown in Figure 25.27*b*. The two valves along the distribution line allow flows to the building or hydrant, although part of the nearby distribution line is shut down. The third valve on the stub side allows the building or hydrant to be isolated without disrupting flows along the water main.

Valves are also commonly located where the distribution line has been downsized. As the number of service connections decreases on the line—for instance, at a terminating street—the distribution line's diameter can be reduced because of the reduced demand. A reducer is a component that allows for the connection of a large pipe to a smaller pipe. As an economic consideration, valves are typically placed after the reducer on the side with the smaller diameter.

The number and location of valves in a development project are a function of the density. In the low- and moderate-

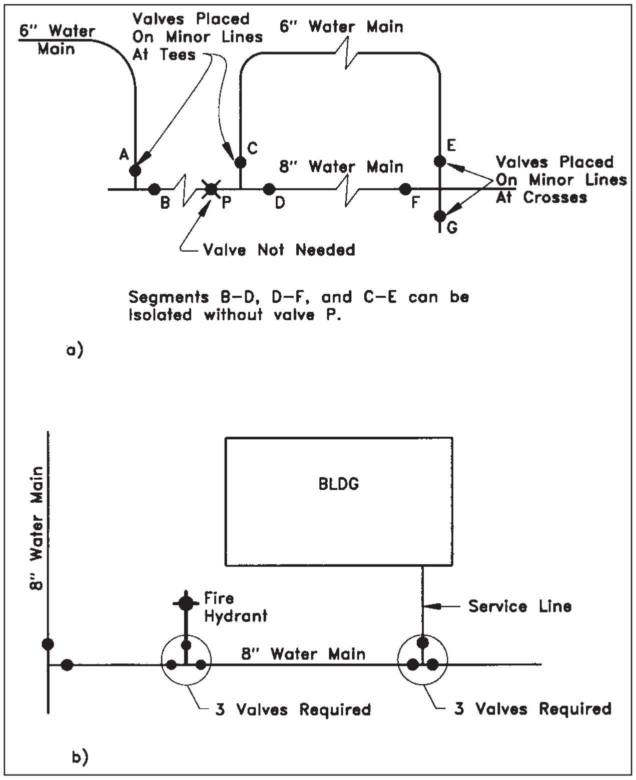


FIGURE 25.27 Valve placement.

density areas, the placement of valves every ±500 feet is inherent due to the street layout. In areas of higher densities (e.g., 10 du/ac or apartment complexes), the placement of valves at 500-foot intervals would mean inconveniencing numerous households when a section is shut down. In such cases the location of valves depends on the number of service lines that can comfortably be shut down. A reasonable range is 15 to 25 service lines between isolation valves. To do this requires intermediate valves placed on the line to limit the number of households to a reasonable level.

Valves are installed in cast-iron or PVC valve boxes with a sleeve placed over the valve that prevents backfilling and allows access from the ground level. The valve box and its lid present a nuisance when located in lawns. When possible, the valve should be placed in accessible areas, but not where the valve box would be covered with soil and overgrown vegetation (e.g., wooded areas). Although locating valves in such areas should be avoided, this is not always possible. In such instances, the valve is enclosed within a vault. The vault may be concrete or another permanent enclosure that protrudes above the ground surface at least 6 inches. A vent stack may also be connected to the vault. The protruding vault and vent stack allow the valve to be located much more easily.

Placement of valves for isolation purposes can be very subjective. Occasionally, the water supply company dictates the location of valves and other controlling components. The water supply company has immediate access to information not readily available to the project engineer. The project engineer can then only make the best guess using the foregoing concepts and personal experience for showing waterline and component location on the plan sheets.

Fire Hydrant Location

Although aesthetic value of a development has a high priority, there is very little compromise with safety and fire protection. Fire hydrants need to be conspicuously located and highly accessible. Firefighters in the throes of fighting a blaze need to locate a hydrant by quick glances in obvious directions. Typically, fire hydrants are located 2 to 3 feet behind the curb or edge of pavement. The hydrant is oriented so that the pumper connection faces the street or travelway and is set far enough behind the face of the curb to avoid damage from vehicles. Hydrants are placed to be accessible for hose connections and the pumper truck and, therefore, should not be placed high on embankments, in depressions or ditches, or near trees, poles, or walls, or where there is insufficient clearance for hose lines (Figure 25.28).

In high-density residential areas (e.g., town house and condominium sites), fire hydrants are frequently placed on parking islands near buildings. Consideration is given to the minimum distance between the fire hydrant and the closest building it is intended to serve. Local codes prescribe the safe distance for which the firefighters can access a hydrant without sustaining injury from the burning building (approximately 50 to 75 feet). Therefore, several hydrants may be needed throughout high-density and commercial areas to protect the building. Another consideration when locating hydrants is the placement of fire hoses. For example, Building Officials Code Administrators (BOCA) fire codes do not recommend placement of unprotected fire hoses across travelways. Placement of fire hydrants on both sides of the street to protect the building opposite the fire hydrant will not suffice because of the BOCA restrictions on placement of fire hoses.

On commercial sites, hydrant spacing is governed by the estimated coverage as determined by fire flow requirements, the course of the unrolled fire hose, and the location of fire hose connections on the building (in addition to any other local requirements). Since fire hoses are unrolled along the travelways and grassy areas, the distance between hydrants is not measured along a straight line connecting the hydrants. Subsequently, for streets and travelways with many short-radius curves and obstructions (e.g., fences and walls) more fire hydrants will be needed. Commercial buildings may be required to have an exterior fire hose manifold (e.g., standpipe, siamese connections). The location of this manifold on the building must be near a fire hydrant, probably within 100 feet.

The International Standards Organization (ISO) recommends hydrant distribution according to the coverage presented in Table 25.11. Rule-of-thumb hydrant spacing ranges from 300-foot to 1000-foot intervals. Actual spacing considers the type and size of the dwelling, land use, risk

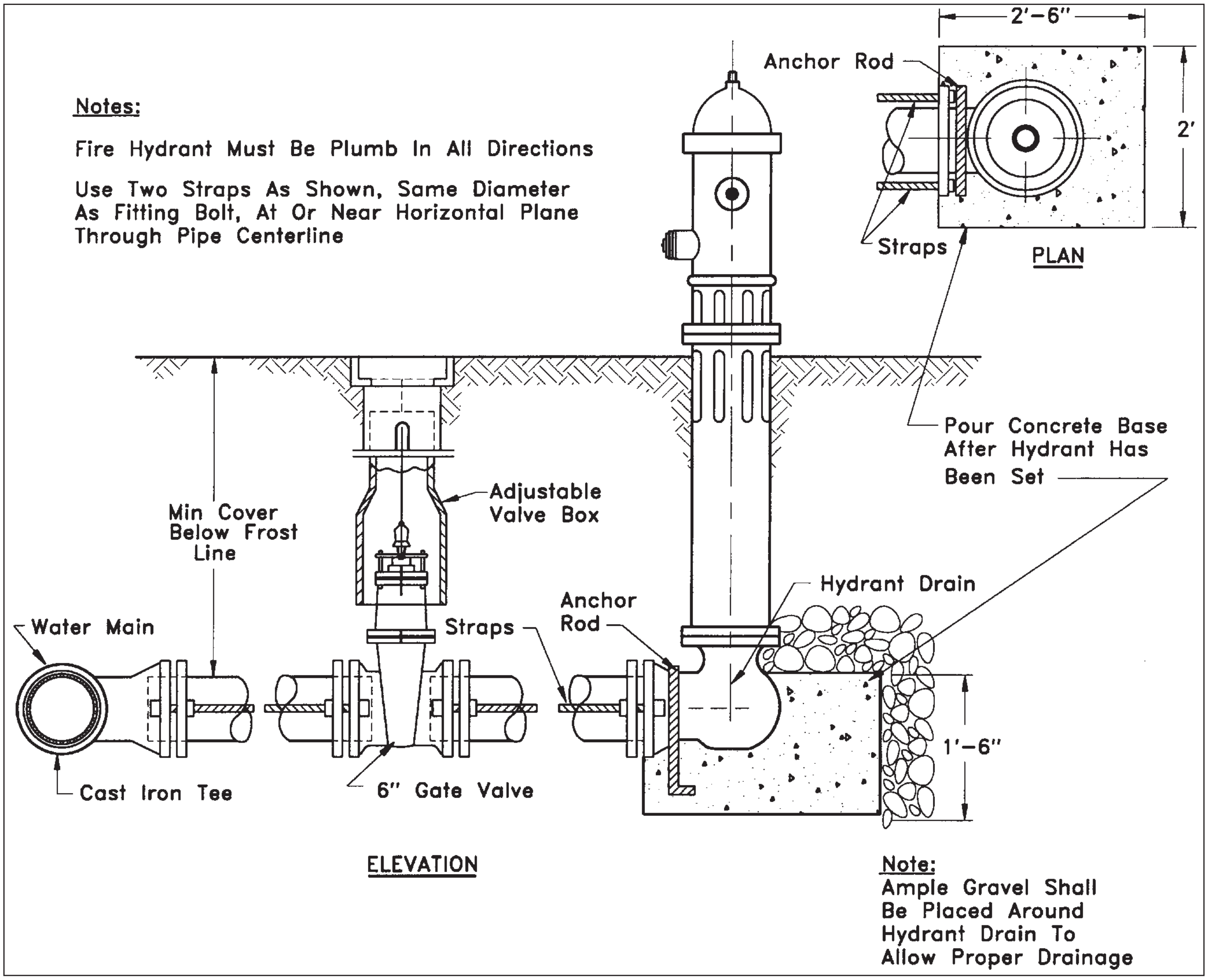


FIGURE 25.28 Typical hydrant settings.

(e.g., a high-value district in terms of property cost and public safety), and local controlling ordinances.

To the extent possible, placement of hydrants should not detract from the streetscape. The fire hydrant needs to be visible and accessible to the firefighters and yet not be obtrusive. For example, in single-family detached subdivisions a hydrant placed behind the curb at the side property line would serve both purposes. A fire hydrant in the middle of the front property line may be unattractive, especially if the house sits close to the front property line.

In placing fire hydrants in a residential subdivision, a systematic method would be to start on the cul-de-sac streets. Determine the fire flow coverage or the maximum distance from fire hydrant to the farthest buildings as prescribed by local codes. Using this distance, place the fire hydrant as far away from the houses within the cul-de-sac as this distance allows. Proceed along the cul-de-sac street toward the through street, placing fire hydrants at the appropriate distances and considering hydrant spacing and prescribed maximum distances to dwellings. After all cul-de-sac streets have the appropriate number of hydrants, the hydrants along through streets are located to provide fire protection not covered by the cul-de-sac fire hydrants or any existing fire hydrants.

A map showing hydrant and valve locations, such as the one in Figure 25.29, might be available from the water utility company or Department of Public Works. A copy of a map such as this for the project area should be obtained prior to beginning the design. This provides information for assessing water availability and hydrant location during the site analysis phase (see Chapter 5).

Pipe Curvature

Gradual change of direction with pipe is accomplished by using bends or simulating curvature through succeeding deflection of pipe joints. The approximate radius of curvature depends on the type of pipe joint, length of pipe, and pipe diameter. Figure 25.30 shows joint deflections for mechanical and push-on pipe joints.

TABLE 25.11 Standard Hydrant Distribution

FIRE FLOW REQUIRED (GPM)	AVERAGE AREA PER HYDRANT (FT^2)
1000 or less	160,000
1500	150,000
2000	140,000
2500	130,000
3000	120,000
3500	110,000
4000	100,000
4500	95,000
5000	90,000
5500	85,000
6000	80,000
6500	75,000
7000	70,000
7500	65,000
8000	60,000
8500	57,500
9000	55,000
10,000	50,000
11,000	45,000
12,000	40,000

Connections

During construction, building service connections are extended from the water main to the right-of-way line. Whereas the water main may be a 6- to 12-inch diameter pipe, the service connections for residential dwellings are typically ¾- to 1-inch diameter. A corporation stop assembly (see Figure 25.31) connects the service line to the water main at a point above the horizontal center of the water main. This location does not draw off any sediment from the bottom of the water main, is an easily accessible location for repairs, and allows trapped air to escape from the water main and be expelled through water fixtures. However, the specific location of the connection depends on the policy of the utility company.

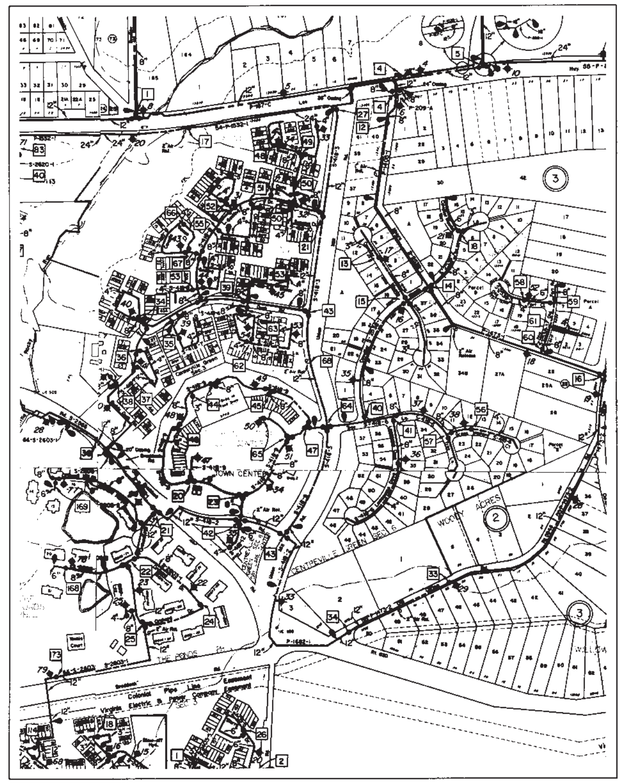


FIGURE 25.29 Municipal map showing waterline, valve, and hydrant location in residential area.

The service connection ends at the meter box or curb box. The meter box contains the shutoff service valve, a yoke, and the water meter. The yoke is a special fitting to hold the service pipe stubs at the proper alignment for connecting the meter. The service box contains only the service valve. In some areas, the building contractor is responsible for installation of the meter and the service line leading to the house and, in others, the water utility company manages the installation of the water main and service lines. The stubbed service lines are installed during construction of the water main. This allows the house connections to be made, as the houses are built without cutting into new pavement.

Connecting to an Existing Waterline

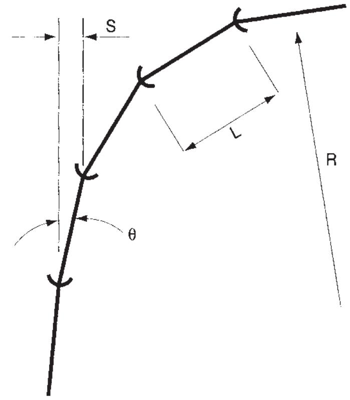
Special types of construction methods are used to connect the proposed water main to an existing water main when the existing service cannot be shut down—even for the short time needed to make the connection. The type of method selected depends on the specific site conditions and the locality.

One common method uses a tapping sleeve and valve. As illustrated in Figure 25.32, the tapping sleeve and valve consists of two half sections of pipe that are strapped over the existing line. Special equipment designed to fit over a valve cuts a hole in the existing water main through the opened valve fixture. After the hole is cut, the equipment is withdrawn and the valve is closed. The water main is extended

Pipeline Curve Geometry

θ = deflection angle
S = joint deflection offset
L = laying length
R = radius of curve

$$R = \frac{L}{2 \tan \frac{\theta}{2}}$$



Maximum Joint Deflection Full-Length Pipe—Mechanical-Joint Pipe

Nominal Pipe Size *in.*	Deflection Angle–θ *deg*	Maximum Offset—S *in. (m)* L = 18 ft (5.5 m)		Maximum Offset—S *in. (m)* L = 20 ft (6.1 m)		Approx. Radius of Curve—R Produced by Succession of Joints *ft. (m)* L = 18 ft (5.5 m)		Approx. Radius of Curve—R Produced by Succession of Joints *ft. (m)* L = 20 ft (6.1 m)	
3	8–18	31	(0.79)	35	(0.89)	125	(38)	140	(43)
4	8–18	31	(0.79)	35	(0.89)	125	(38)	140	(43)
6	7–07	27	(0.69)	30	(0.76)	145	(44)	160	(49)
8	5–21	20	(0.51)	22	(0.56)	195	(59)	220	(67)
10	5–21	20	(0.51)	22	(0.56)	195	(59)	220	(67)
12	5–21	20	(0.51)	22	(0.56)	195	(59)	220	(67)
14	3–35	13.5	(0.34)	15	(0.38)	285	(87)	320	(98)
16	3–35	13.5	(0.34)	15	(0.38)	285	(87)	320	(98)
18	3–00	11	(0.28)	12	(0.30)	340	(104)	380	(116)
20	3–00	11	(0.28)	12	(0.30)	340	(104)	380	(116)
24	2–23	9	(0.23)	10	(0.25)	450	(137)	500	(152)
30	2–23	9	(0.23)	10	(0.25)	450	(137)	500	(152)
36	2–05	8	(0.20)	9	(0.23)	500	(152)	550	(167)
42	2–00	7.5	(0.19)	8	(0.20)	510	(155)	570	(174)
48	2–00	7.5	(0.19)	8	(0.20)	510	(155)	570	(174)

Maximum Joint Deflection* Full-Length Pipe—Push-On Type Joint Pipe

Nominal Pipe Size *in.*	Deflection Angle–θ *deg*	Maximum Offset—S *in. (m)* L = 18 ft (5.5 m)		Maximum Offset—S *in. (m)* L = 20 ft (6.1 m)		Approx. Radius of Curve—R Produced by Succession of Joints *ft. (m)* L = 18 ft (5.5 m)		Approx. Radius of Curve—R Produced by Succession of Joints *ft. (m)* L = 20 ft (6.1 m)	
3	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
4	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
6	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
8	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
10	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
12	5	19	(0.48)	21	(0.53)	205	(62)	230	(70)
14	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
16	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
18	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
20	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
24	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
30	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
36	3*	11	(0.28)	12	(0.30)	340	(104)	380	(116)
42	2*	7.5	(0.19)	8	(0.20)	510	(155)	570	(174)
48	2*	7.5	(0.19)	8	(0.20)	510	(155)	570	(174)
54	1 1/2*	5.5	(0.14)	6	(0.15)	680	(207)	760	(232)

* For 14-in. and larger push-on joints, maximum deflection angle may be larger than shown above. Consult the manufacturer.

FIGURE 25.30 Joint deflections for mechanical and push-on joints. (Reprinted by permission from American Water Works Association Standard for Ductile Iron Water Mains and Their Appurtencances. Copyright © 1993, American Water Works Association)

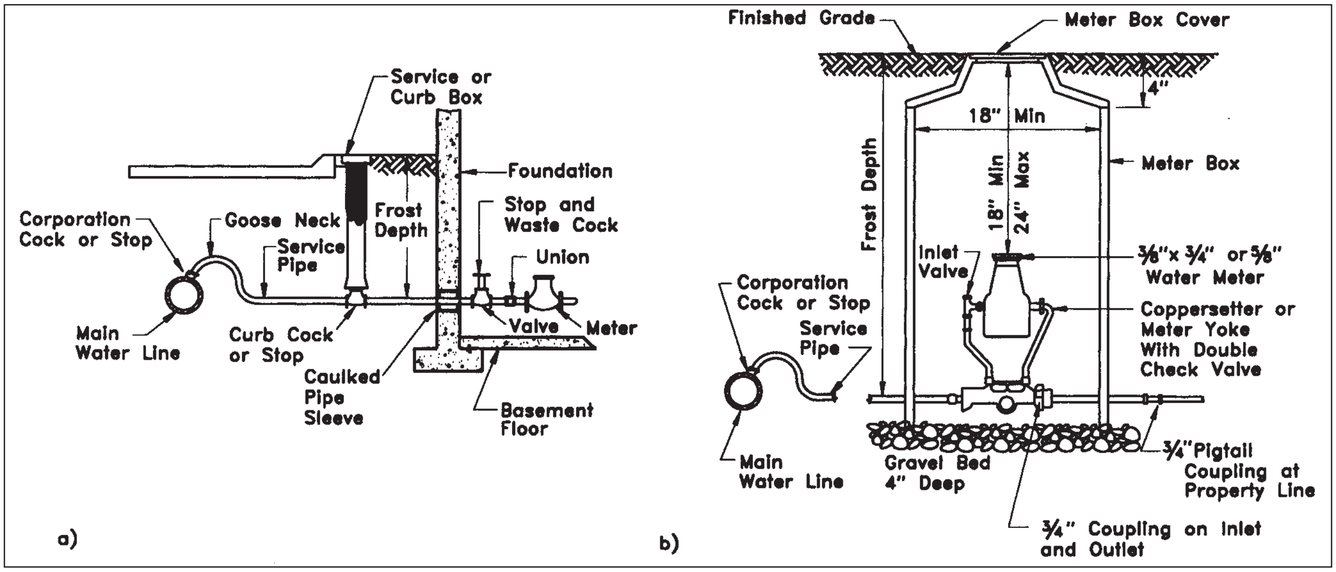


FIGURE 25.31 Typical service connections.

and the valve is opened when the extended water main has been approved for service. The advantage of the tapping sleeve and valve is that it does not require existing service to be shut down while the connection is made. However, this type of connection, sometimes referred to as a wet tap, can be expensive.

If isolation valves are located in close proximity to the proposed connection, they can be closed while the connection is made. While the valves are closed, the existing pipe can be cut. The cut section is removed, and a tee and sleeve is inserted in its place. Note that this method requires inconveniencing the customers while the construction is performed.

Another method, similar to the wet tap method, consists of inserting valves onto the existing line in the area where the connection is to be made. The valves are closed and the existing waterline is cut and replaced by the fixture. However, like the wet tap, this method can be expensive.

Many connections of appurtenances require additional stability due to pressure forces. Besides using thrust blocks, stability is attained by strapping the appurtenances to other stable parts. Strapping consists of connecting one fixture to another fixture or pipe by using several rods attached at the flanges.

Cross Connections

A cross connection is a link through which contaminated water enters the potable water supply. The most obvious situation in which this occurs is when the potable water supply is directly connected to a contaminated source, either through an error during construction or poor hydraulic design. Although the system of checks and balances that exists during the design and approval process minimizes the chances of such a connection occurring, the repercussions of even one occurrence are costly both in human safety and monetary damages. Even if not physically connected to the water supply system, cross connections can occur when back siphonage and backflows of contaminated water enter the potable water system. Back siphonage, a type of backflow, results from negative pressures within the distributing pipes of the potable water supply, which draw water from the surrounding area into the system. Back siphonage can occur from inadequate pressure at the suction side of a booster pump, a water main break causing significantly reduced pressure in the system, and reduced pressure in the system caused during repairs.

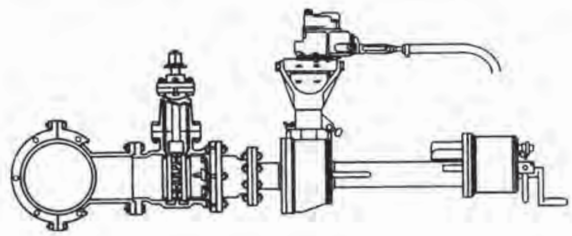
An actual situation where contamination of the water supply resulted from backflow occurred in 1971. As reported by the EPA:

> A contractor using a tank truck with a rig designed to pump and spray a mixture of water, fertilizer, grass seed and wood pulp was working on the grounds of a subdivision. The contractor was using a direct connection to a fire hydrant to fill the tank with water, which was then mixed with the fertilizer, etc. A high pressure pump then sprayed the mixture onto the ground. As the wood pulp circulated through the tank piping system, it plugged one of the lines while the pump continued to run creating a very high pressure in the tank. This pressure was higher than the water supply system pressure and it forced the solution of fertilizer into the water system. Several people in the subdivision became ill after drinking the water, but the contamination was discovered and quick action in flushing and disinfecting the lines eliminated the danger.[2]

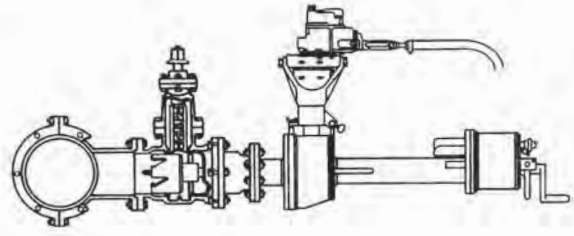
Although certain precautionary measures can be used to reduce the potential for cross connection during the design, the potential will always exist as long as the human element is present in design and construction. The most direct and

[2] Cross Connection Control Manual, USEPA 1975.

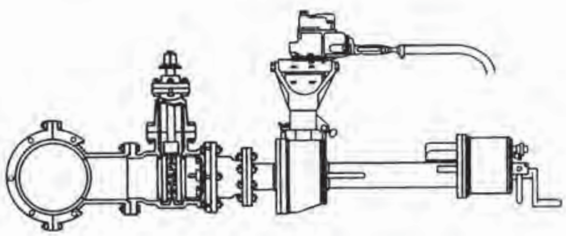
The MUELLER method for making a lateral connection using the MUELLER CL-12 Drilling Machine



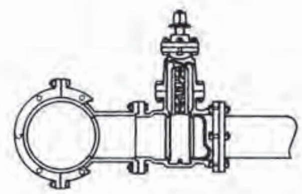
1 The tapping sleeve and valve are first attached to the main and tested. Then the drilling machine, with a shell cutter attached to the boring bar, is attached to the tapping valve using an adapter. The assembly should be pressure tested prior to making the cut.



2 With the tapping valve open, the shell cutter and boring bar are advanced to cut the main.



3 The boring bar is retracted and the tapping valve closed to contain the water pressure.



4 With the machine removed, the lateral is connected and the tapping valve opened to pressurize the lateral and place it in service.

Large drilling machine selection guide

Machine	Tapping valve size range	Maximum pressure	Operation	Recommended uses
CL-12	2"-12"	250 psig (1724 kPa)	Hand or power	For making lateral connections or inserting valves under pressure
C1-36-99002	2"-24"	500 psig (3447 kPa)	Hand or power	
CC-25	2"-12"	500 psig (3447 kPa)	Hand	

FIGURE 25.32 Tapping sleeve and valve. (Reprinted with permission of Mueller Co., Decatur, IL)

easiest method for backflow prevention is the inclusion of an air space between the free-flowing discharge end of the pipe and the flood-level rim of the fixture. Other mechanical methods, used mainly in the smaller distribution and service lines, include vacuum breakers, double check valve, and reduced-pressure-principle device.

SYSTEM ANALYSIS

Analysis and design of a water distribution system is a complex process. As a result of the availability of computers and the myriad software programs available to analyze complex systems, detailed longhand computations have become virtually obsolete. This does not de-emphasize the importance of the fundamental knowledge of hydraulics. Very often, the computer and software are used as a "black box" to generate answers from the input data. Although it is not imperative that the program users fully understand the program and the numerical methods used within the program, it is imperative that the users understand the limitations of the program and the reliability of the input data. To intuitively get a feel for the correctness of the output, the engineer still needs to understand the fundamental methods typically used in the software program. The results from a computer software program are only as good as the input data and the numerical methods used within the program.

Pipe Flow

In general, flow through a pipe conduit is affected by its hydraulic and geometric properties. Length and shape are the significant geometric properties; hydraulic properties include pipe material (for roughness), type and number of components (valves, reducers, bends, tees, etc.), and pressure. Analysis of fluid flow is a matter of determining the total hydraulic energy of the fluid. To do so requires the conversion of the fluid's known energy-related parameters—pressure, velocity, and relative elevation—to units of energy.

Most water distribution systems function as pressure flow. Mathematically, system pressure is converted to energy by changing the units of pressure to an equivalent height of fluid. This is done by dividing the pressure by the specific weight of the fluid. Although specific weight is a function of temperature, the value of 62.4 pounds per cubic foot is ordinarily assumed constant for the conditions encountered in water distribution systems. Equation 25.13 converts pressure to pressure head—the depth of fluid that creates a pressure identical to the pressure in the pipe.

$$\frac{p}{\gamma} = h \tag{25.13}$$

where p is the pipe pressure in lb/ft^2, γ is the specific weight of the fluid (lb/ft^3), and h is a depth in ft. This is also referred to as the flow energy of the fluid. The kinetic energy of a moving fluid, typically referred to as the velocity head, is

$$h_v = \frac{v^2}{2g} \tag{25.14}$$

where h_v = velocity head, v = average velocity in the cross section of flow, and g = gravitational acceleration.

Fluid within the distribution system also has potential energy. This is the energy associated with a fluid's height relative to a reference datum. The datum is arbitrarily selected for the convenience of analyzing the system or identifying other parameters associated with the system. The variable z is used in hydraulic nomenclature to reference the potential energy of the system.

Analysis of a system, or components within specific confines of the system, usually requires the comparison of the total energy of the fluid at two locations. From the conservation of energy principle, equating the energy at one location to the fluid's energy at the second location produces

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 + \Sigma h_i = \frac{p_2}{\gamma} + \frac{v_1^2}{2g} + z_2 + \Sigma h_L \tag{25.15}$$

where the Σh_L terms represent energy lost by the fluid in going from location one to location two. Energy lost or taken from the system is attributed to pipe friction, components such as valves and reducers, and sudden enlargements and contractions.

In the energy equation (Equation 25.13), the $p/\gamma + z$ terms represent the hydraulic grade line (HGL). This is the locus of values above the centerline of the pipe that designate the height to which the water level would rise due to the pressure head if it were not confined within the pipe. Along straight sections of pipe, energy losses in the system cause the HGL to drop in the direction of flow. However, increases in pipe velocity in the downstream direction will cause the HGL to rise. Adding the $v^2/2g$ term to the HGL represents the energy grade line. This represents the fluid's available energy and, similar to the HGL, decreases in the downstream direction when no external energy is put into the system.

Discharge through pipes is represented by the continuity equation, $Q = VA$. Unless there is a leak or the fluid is highly compressible, the continuity equation shows that the amount of water flowing in a length of pipe is constant; velocity adjusts proportionally to any change in cross-sectional area to keep the discharge constant. Inherent in pipe flow is the energy loss from the effects of the roughness of the pipe material. The pipe's surface roughness affects the velocity across the cross-sectional flow area, with a net result of retarding the flow. Therefore, the equations for determining the discharge in pipes must account for this head (i.e., energy) loss.

The Darcy-Weisbach equation is one of the most popular methods for determining the head loss in pipe flow:

$$h_L = f\frac{L}{D}\frac{V^2}{2g} \tag{25.16}$$

where h_L = head loss, f = dimensionless friction factor, L = length of pipe, D = diameter of the pipe, V = average velocity in the pipe, and g = gravitational constant. Experimental verification shows the following to be true:

- The head loss varies directly with the length of pipe and inversely with the diameter.
- The head loss varies with the square of the velocity.
- The head loss depends on the roughness of the interior pipe wall.
- The head loss depends on fluid properties of density and viscosity and is independent of pressure.

The last two items are evident from the significance of the parameter *f*. The value of *f* is dependent on the Reynolds number, the ratio of the inertia forces to the viscous forces of the fluid, and the relative roughness of the pipe. These are the only two significant forces of the fluid in a completely filled conduit. For a circular conduit the Reynolds number (R) is

$$R = \frac{\rho DV}{\mu} \tag{25.17}$$

For laminar flows (i.e., R < 2000),

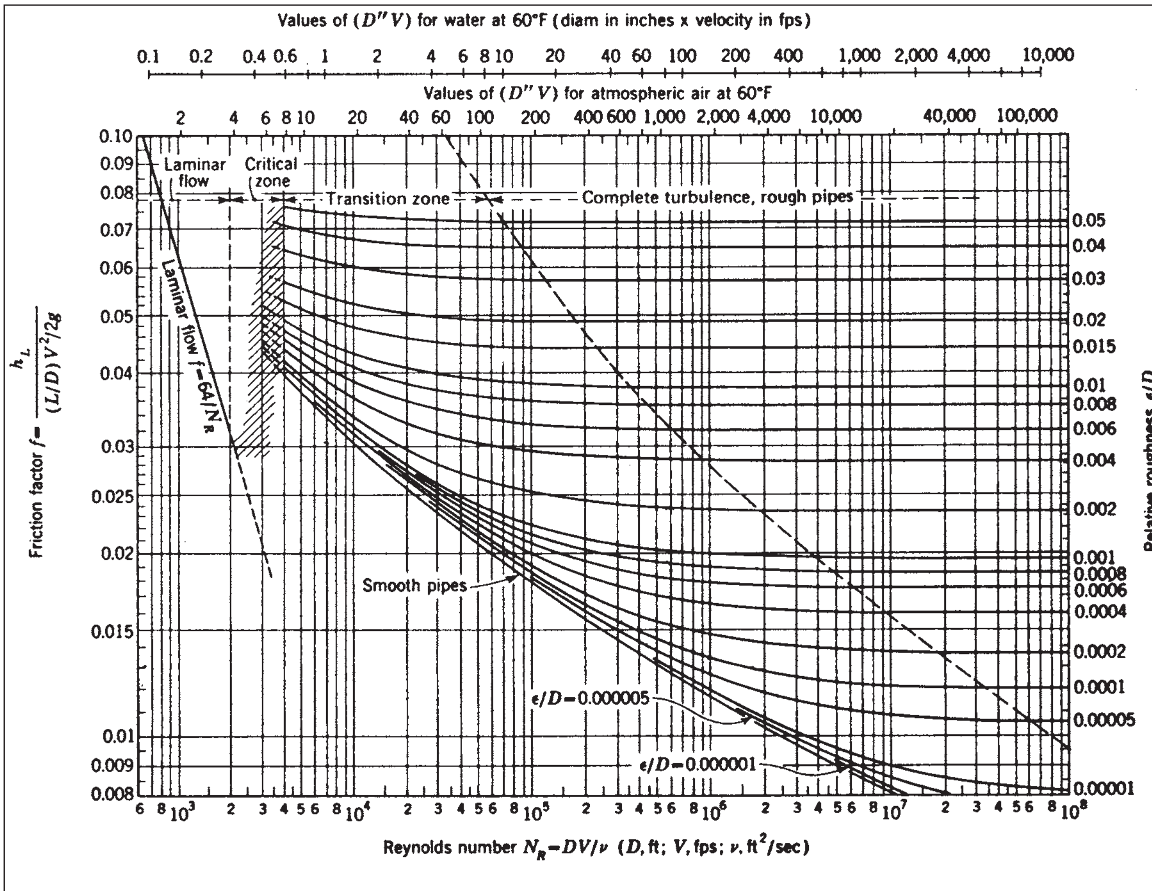
$$f = \frac{64}{R} \tag{25.18}$$

where ρ is the density and μ is the absolute viscosity of the fluid. For any consistent system of units, R is a dimensionless number.

For turbulent flows, *f* has been found through experimentation to be related to the ratio of ε/D, where ε is the absolute roughness, a parameter that measures the size of the irregularities of the pipe material. The Moody diagram (Figure 25.33) shows the relationship between *f*, ε, and R. This ratio depends on the pipe material and the pipe diameter. Figure 25.34 shows this ratio for various commercial pipes.

The energy loss h_L for a known discharge and pipe can be found by the following process:

1. Determine the Reynolds number (Equation 25.17).
2. Determine ε from Figure 25.34.
3. Determine the ε/D ratio and enter R and ε/D on the Moody diagram (Figure 25.34) and read the corresponding value of *f*.
4. Use the Darcy-Weisbach (Equation 25.16) to find h_L.
5. Use the Bernoulli equation and/or the continuity equation to determine other design parameters.



Friction factor for pipes.

FIGURE 25.33 Moody diagram. (ASME Transactions, vol. 66, 1944. Reprinted by permission of American Society of Mechanical Engineers)

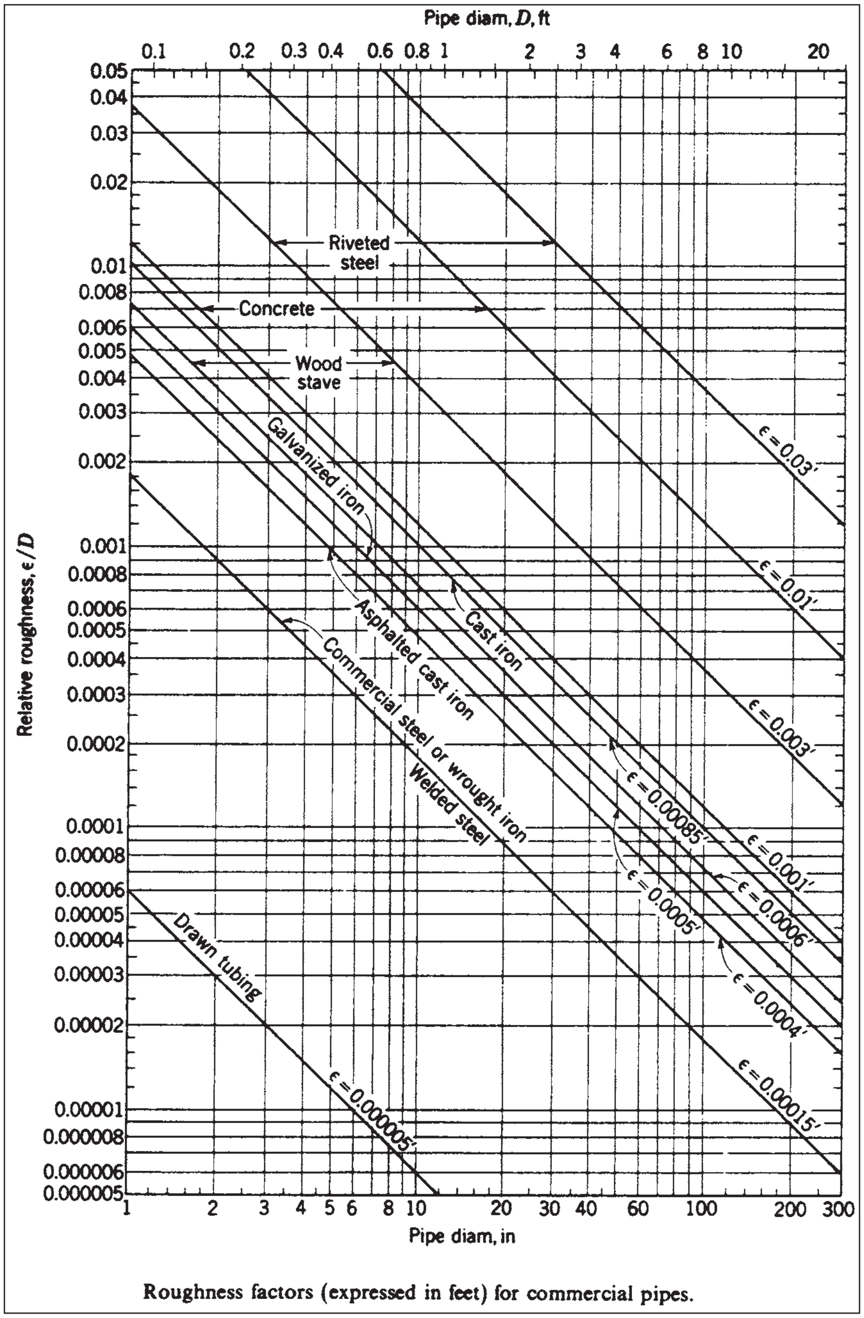


FIGURE 25.34 Roughness factors for commercial pipes. (ASME Transactions, vol. 66, 1944. Reprinted by permission of American Society of Mechanical Engineers)

In lieu of the Moody diagram, Equation 25.19 can be used to approximate f for the given constraints

$$f = \frac{1.325}{[\ln(\varepsilon/3.7\,D + 5.74/\mathrm{R}^{0.9})]^2} \tag{25.19}$$

for

$$10^{-6} \le \frac{\varepsilon}{D} \le 10^{-2}$$

$$5000 \le \mathrm{R} \le 10^{8}$$

Pipe analysis problems with incompressible flow require the determination of the variables Q, L, D, h_f, and V. Recognize that V, D, and f are interrelated. Hence, the solution to solving problems where these parameters are unknown (and therefore R is unknown) requires a trial-and-error procedure. Since the value of f changes very slowly at the higher R values, begin the trial-and-error procedure by assuming a value for either f or R and obtain a final solution for Q or V. Compute an f (or R) using the final solution, and use the Moody diagram to find R (or f) and compare this to the assumed value. The procedure ends when the computed value is within an acceptable tolerance of the assumed value. For example, if D is known, the trial-and-error procedure begins by assuming f and using the Darcy-Weisbach equation to find the velocity. Use this velocity to compute R and find the corresponding f value from the Moody diagram. If the two values are within an acceptable tolerance, the procedure ends and the design parameters are known; otherwise, assume another value for f and repeat the procedure.

Another popular method used to find pipe discharges and other design parameters is the Hazen-Williams equation, shown for use with English units as

$$V = 1.318\, C\, R^{0.63}\, S^{0.54} \tag{25.20}$$

where V = velocity, C = coefficient associated with pipe roughness, R = hydraulic radius (= $D/4$ for circular pipes flowing full), and S = energy gradient (h_L/L).

Although not dimensionally correct, as many empirical equations tend to be, the Hazen-Williams equation provides generally acceptable discharge estimates. In most problems for design purposes, C is taken to be 100 but, for aged pipe C, can be as low as 70. Table 25.12 provides a range of C values for different pipe materials. The advantage in using this equation, over the Darcy-Weisbach equation, is the independence of C from the Reynolds number. Because this equation does not include any terms relating to the physical properties of the fluid, the Hazen-Williams equation is used for water discharges for turbulent conditions only. Additionally, this nondependence on the physical properties of the water makes the Hazen-Williams equation the preferred equation for pipe flow analysis. Figure 25.35 is the nomograph for the Hazen-Williams equation. Given the value of two of the variables in the equation, the nomograph provides the unknown values of the remaining two variables.

Minor Losses

Components in the pipe network contribute to the system's head losses. These are considered as minor losses and, depending on the section of the system under analysis, may or may not need to be incorporated into the design computations. Energy lost through friction is significantly larger than the combined minor losses when pipe lengths exceed 1000± diameters. In these situations, the minor energy losses can be ignored without appreciable effect on the results (due to the uncertainty in the C coefficient).

The loss coefficient method uses a constant of proportionality based on the configuration of the component. This constant is applied to the velocity head of the water entering or exiting the component. This method computes the minor losses using the form

$$h_v = k\frac{v^2}{2g} \tag{25.21}$$

where k is the constant of proportionality. Table 25.13 shows k factors for various fittings and other waterline appurtenances. For additional information on head losses through fittings as well as other components, the manufacturer's specifications should be consulted.

Equivalent Pipe Lengths

A pipe network typically consists of loops and branches, with fittings and pipes of various diameters. In order to simplify pipe network computations, it may be advantageous to convert the fittings and various pipe lengths into equivalent lengths of a uniform diameter. The equivalent pipe length represents a length of pipe of known diameter that has either the same head loss as a length of pipe of different diameter with the same discharge or the same head loss as a fitting for the given discharge. Using the Darcy-Weisbach equation, an equivalent-length pipe for a fitting with a given head loss is

$$f\left(\frac{L_e}{D}\right)\frac{V^2}{2g} = K\left(\frac{V^2}{2g}\right) \tag{25.22}$$

$$L_e = K\frac{D}{f}$$

where the terms are as defined earlier and L_e represents the length of pipe of diameter D that corresponds to the head loss through the component. The nomograph of Figure 24.30 can be used in lieu of the equations to convert various fixtures to equivalent lengths.

To convert a pipe of one diameter to a pipe of different diameter for a given discharge, either the Darcy-Weisbach equation or the Hazen-Williams equation can be used. After rearranging terms of the Darcy-Weisbach equation by converting one pipe of known diameter D to another diameter D_e of equivalent length, L_e is found by

$$L_e = L\left(\frac{f}{f_e}\right)\left(\frac{D_e}{D}\right)^5 \tag{25.23}$$

where f and f_e are, respectively, the friction factors for the given pipe and equivalent-length pipe.

Similarly, the Hazen-Williams equation is rearranged to find an equivalent-length pipe by using the diameters and the coefficients of pipe roughness for the equivalent-length pipe C_e and the coefficient of roughness for the given pipe C:

$$L_e = L\left(\frac{D_e}{D}\right)^{4.87}\left(\frac{C_e}{C}\right)^{1.85} \tag{25.24}$$

As an example, find the equivalent length of 12-inch diameter ductile iron pipe (C = 100) for 500 feet of 10-inch-diameter pipe (C = 100) attached with a globe valve at one end (Q = 5 cfs).

The velocity in the 10-inch pipe is:

$$V_{10} = \left(\frac{Q}{A_{10}}\right) = \frac{5}{\frac{\Pi}{4}\left(\frac{10}{12}\right)^2} = 9.2 \text{ fps} \tag{25.25}$$

Using the same equation, the velocity in the 12-inch diameter pipe is 6.4 fps.

From Table 25.13 the head loss coefficient for a globe

TABLE 25.12 Relative Roughness and Hazen-Williams Constants for Various Pipe Materials

	ε(FT)		*C*		
Type of pipe or Surface	**Range**	**Design**	**Range**	**Clean**	**Design**
STEEL					
welded and seamless	0.0001–0.0003	0.0002	150–80	140	100
interior riveted, no projecting rivets				139	100
projecting girth rivets				130	100
projecting girth and horizontal rivets				115	100
vitrified, spiral-riveted, flow with lap				110	100
vitrified, spiral-riveted, flow against lap				100	90
corrugated				60	60
MINERAL					
concrete	0.001–0.01	0.004	152–85	120	100
cement-asbestos			160–140	150	140
vitrified clays					110
brick sewer					100
IRON					
cast, plain	0.0004–0.002	0.0008	150–80	130	100
cast, tar (asphalt) coated	0.0002–0.0006	0.0004	145–50	130	100
cast, cement-lined	0.000008	0.000008		150	140
cast, bituminous-lined	0.000008	0.000008	160–130	148	140
cast, centrifugally spun	0.00001	0.00001			
galvanized, plain	0.0002–0.0008	0.0005			
wrought, plain	0.0001–0.0003	0.0002	150–80	130	100
MISCELLANEOUS					
fiber				150	140
copper and brass	0.000005	0.000005	150–120	140	130
wood stave	0.0006–0.003	0.002	145–110	120	110
transite	0.000008	0.00008			
lead, tin, glass		0.000005	150–120	140	130
plastic (PVC and ABS)		0.000005	150–120	140	130

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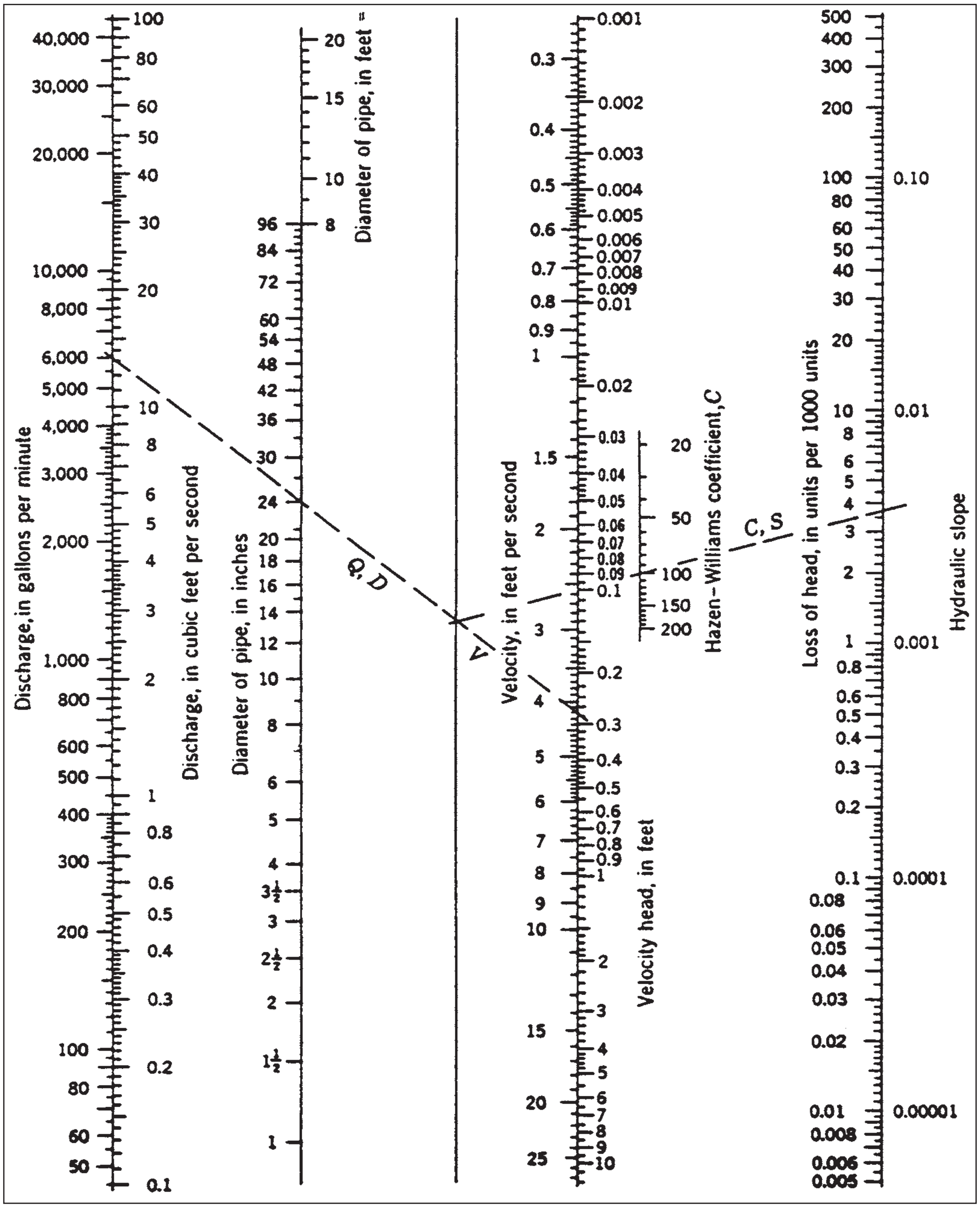


FIGURE 25.35 Hazen-Williams nomograph. Design and construction of sanitary and storm sewers (1969). (American Society of Civil Engineers and the Water Pollution Control Federation. Reprinted with permission of ASCE, New York)

valve is 10 and the corresponding head loss through the globe valve is:

$$h_l = 10\left(\frac{9.2^2}{2g}\right) = 13.1 \text{ ft} \tag{25.26}$$

Using the Hazen-Williams equation, the equivalent length of 12-inch diameter pipe for the globe valve is:

$$L_{12} = \left(\frac{1.318CR^{0.63}h_L^{0.54}}{V}\right)^{1.85} \tag{25.27}$$

$$= \frac{1.318(100)\left(\frac{1}{4}\right)^{0.63} 13.1^{0.54}}{6.4} = 700 \text{ ft}$$

From Equation 25.24, the equivalent length of 12-inch-diameter pipe for 500 feet of 10-inch-diameter pipe is

$$L_{12} = 500\left(\frac{1}{\left(\frac{10}{12}\right)}\right)^{4.87}\left(\frac{100}{100}\right)^{1.85} = 1215 \text{ ft} \tag{25.28}$$

The total equivalent length of 12-inch diameter pipe is 700 + 1215 = 1915 feet.

Fixture Unit Method

Occasionally, the project engineer may be required to size the water service line to a building. This normally occurs on commercial or other high-rise/high-density projects. For the most part, however, the analysis and sizing of the internal

TABLE 25.13 Table of Local Loss Coefficients

Use the equation $h_v = kv^v/2g$ unless otherwise indicated. Energy loss E_L equals h_v head loss in feet.

Perpendicular square entrance:

$k = 0.50$ if edge is sharp

Perpendicular rounded entrance:

$R/d =$	0.05	0.1	0.2	0.3	0.4
$k =$	0.25	0.17	0.08	0.05	0.04

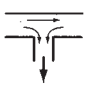
Additional loss due to skewed entrance:

$k = 0.505 + 0.303 \sin\alpha + 0.226 \sin^2\alpha$

Strainer bucket:

$k = 10$ with foot valve
k = 5.5 without foot valve

Standard tee, entrance to minor line:

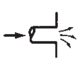


$k = 1.8$

Confusor outlet:

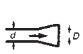
$d/D =$	0.5	0.6	0.8	0.9
$k =$	5.5	4	2.55	1.1

Exit from pipe into reservoir:



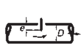
$k = 1.0$

Diffusor outlet for D/d > 2:



$\alpha° =$	8	15	30	45
$k =$	0.05	0.18	0.5	0.6

Gate valve:



$e/D =$	0	1/4	3/8	1/2	5/8	3/4	7/8
$k =$	0.15	0.26	0.81	2.06	5.52	17.0	97.8

Globe valve:

$k = 10$ when fully open

Rotary valve:

$\alpha° =$	5	10	20	30	40	50	60	70	80
$k =$	0.05	0.29	1.56	5.47	17.3	52.6	206	485	∞

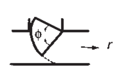
Check valves:

Swing type $k = 2.5$ when fully open
Ball type $k = 70.0$
Lift type $k = 12.0$

Angle valve:

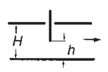
$k = 5.0$ if fully open

Segment gate in rectangular conduit:



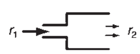
$k = 0.3 + 1.3\,[(1/n)]^2$
where $n = \phi/\phi_0 =$ the rate of opening with respect to the central angle

Sluice gate in rectangular conduit:



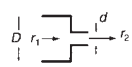
$k = 0.3 + 1.9\,[(1/n) - n]^2$
where $n = h/H$.

Sudden expansion:



$E_L = \left(1 - \frac{v_2}{v_1}\right)^2 \frac{v_1^2}{2g}$ or $E_L = \left(\frac{v_1}{v_2} - 1\right)^2 \frac{v_2^2}{2g}$

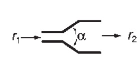
Sudden contraction:



$(d/D)^2 =$	0.01	0.1	0.2	0.4	0.6	0.8
$k =$	0.5	0.5	0.42	0.33	0.25	0.15

use v_2 in Equation 13.13

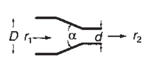
Diffusor:



$E_L = k(v_1^2 - v_2^2)/2g$

$\alpha° =$	20	40	60	80
$k =$	0.20	.028	0.32	0.35

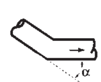
Confusor:



$E_L = k(v_1^2 - v_2^2)/2g$

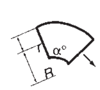
$\alpha° =$	6	10	20	40	60	80	100	120	140
$D = 3d$	0.12	0.16	0.39	0.80	1.0	1.06	1.04	1.04	1.04
D-$1.5d$	0.12	0.16	0.39	0.96	1.22	1.16	1.10	1.06	1.04

Sharp elbow:



$k = 67.6 \times 10^{-6}(\alpha°)^{2.17}$

Bends:



$k = (0.13 + 1.85(r/R)^{3.5})\sqrt{\alpha°/180°}$

Close return bend:

$k = 2.2$

(Courtesy of Simon, Andrew L. *Hydraulics*. 1986. Adopted by permission of Prentice Hall, Inc., Englewood Cliffs, NJ.)

distribution system are typically done by mechanical/plumbing engineers. The size of the water supply line to the building depends on the demand within the building, which may be related to the number and type of plumbing fixtures in the building or perhaps the building's use. Since there are several methods available to estimate the demand, the one used depends on the building codes of that jurisdiction.

The simplest method used to estimate demand is one that relates the demand to the building use. For example, water demand for an office building could be based on the square footage of the floor area or the number of employees, while for apartments the demand may be based on the number of units in the building. If this type of method is used, the demand table for various building uses will be prescribed in the applicable building code.

Another method estimates the demand based on the number and type of plumbing fixtures in the building. However, the size of the water supply line is based on maximum probable demand rather than the sum of the maximum flows of all of the fixtures. It is highly unlikely that every plumbing fixture would be operating at maximum discharge simultaneously. Under this assumption, the demand is related to the number and type of fixtures, the rates required by these fixtures, and the probable simultaneous operation of the fixtures. The unit of measurement used to correlate these flow characteristics is the water supply fixture unit (WSFU).

The fixture unit is a measure of the hydraulic demand of a fixture. It is the average discharge during use of an arbitrarily selected plumbing fixture. It takes into account the anticipated discharge, the average duration of flow when the fixture is in use, and the frequency with which the fixture is likely to be used. The WSFU is a factor chosen so that the load-producing effects of different kinds of plumbing fixtures, as well as their conditions of service, can be expressed as multiples of that factor. For example, if a bathtub with a discharge of 7.5 gpm is selected as the arbitrary fixture, a fixture with a discharge of 22 gpm is assigned a fixture unit of 3.

Typical values of fixture units are given in Table 25.14. By knowing the type and number of water supply fixtures, the total WSFU for a building can be determined and then converted to flow rates using Figure 25.36.[3]

After estimating the peak demand, the service line is sized using head loss and velocity parameters for the pipe material selected. Consideration is given to the available pressure in the water main to determine whether the pressure is adequate for the calculated losses through the building. Booster pumps may be required when pressures are inadequate at the upper-level floors.

[3]This curve, frequently referred to as the Hunter curve, was first proposed by Roy B. Hunter of the National Bureau of Standards in 1923. Since then it has been modified based on other research data.

EXAMPLE 2

Size the water supply line for a three-story apartment building having five apartment units on each level. Each apartment has one bathroom and a kitchen with a dishwasher. There are four (16-lb) laundry machines in the basement. The elevation of the 8-in water main located in the street is 165.5 ft. The water meter, where the service line connects to the building, is 160 ft away from the water main and is at an elevation of 175.5 ft. The service line has two 90° elbows and one angle valve. Minimum pressure in the water main is 45 lb/in^2 (see Table 25.15).

1. Tabulate the fixture units.

2. Using Figure 25.36, the total demand for 151 WSFU is 60 gpm.

3. Using Figure 25.37, the demand discharge of 60 gpm and a design velocity of 6 fps indicates that a 2-in pipe is required. Note that the corresponding pressure drop (i.e., head loss) is 2.8 lb/in^2 per 100 ft.

4. Convert the elbows and angle valve to equivalent lengths of pipe. From Figure 24.30, the angle valve is 28 ft of 2-in pipe and an elbow is 5 ft of 2-in pipe.

5. The pressure at the inlet side of the water meter is the minimum pressure in the water main minus the losses in the valves and piping and the elevation difference (i.e., static lift) between the water main and the outlet connection:

$$\begin{aligned}\text{Pressure @ water meter} &= 45\ \text{lb/in}^2 \\ &\quad - \left[\frac{2.8\ \text{lb/in}^2}{100\ \text{ft}}(160 + 28 + 2(5)) - (174.5 - 164.5)\right] \\ &= 29.5\ \text{lb/in}^2\end{aligned} \tag{25.29}$$

Hardy-Cross

Analysis of a water distribution system can be extremely complex due to the varying pipe sizes, pump storage facilities, fluctuations in demand, and fire flow requirements that must be considered. Many methods used for analysis are iterative processes that incrementally adjust the flows or head losses until convergence. Several iterative techniques include the linear theory method, the Newton-Raphson method, and the ever popular Hardy-Cross method. One of the most widely used and accepted computer models, KYPIPE, is based on the linear theory method.

The simplicity of the Hardy-Cross method, a form of the Newton-Raphson method, lends itself to hand calculations. Although the personal computer has made laborious hand calculations nearly obsolete, an understanding of even the simplest method helps in assessing the validity of the final values of the analysis. The Hardy-Cross method uses an equation of the form

$$h_f = KQ^n \tag{25.30}$$

TABLE 25.14 Demand Load of Fixtures*

Fixture	Occupancy	Type of supply control	Load values assigned, water supply fixture units: Cold	Hot	Total
Water closet	Public	Flush valve	10		10
Water closet	Public	Flush tank	5		5
Urinal	Public	1″ (25.4 mm) flush valve	10		10
Urinal	Public	¾″ (19 mm) flush valve	5		5
Urinal	Public	Flush tank	3		3
Lavatory	Public	Faucet	1.5	1.5	2
Bathtub	Public	Faucet	3	3	4
Showerhead	Public	Mixing valve	3	3	4
Service sink	Offices, etc.	Faucet	2.25	2.25	3
Kitchen sink	Hotel, restaurant	Faucet	3	3	4
Drinking fountain	Offices, etc.	⅜″ (9.52 mm) valve	0.25		0.25
Water closet	Private	Flush valve	6		6
Water closet	Private	Flush tank	3		3
Lavatory	Private	Faucet	0.75	0.75	1
Bathtub	Private	Faucet	1.5	1.5	2
Shower stall	Private	Mixing valve	1.5	1.5	2
Kitchen sink	Private	Faucet	1.5	1.5	2
Laundry trays (1 to 3)	Private	Faucet	2.25	2.25	3
Combination fixture	Private	Faucet	2.25	2.25	3
Dishwashing machine	Private	Automatic		1	1
Laundry machine [8 lb (3.6 kg)]	Private	Automatic	1.5	1.5	2
Laundry machine [8 lb (3.6 kg)]	Public or general	Automatic	2.25	2.25	3
Laundry machine [16 lb (7.3 kg)]	Public or general	Automatic	3	3	4

*For fixtures not listed, loads should be assumed by comparing the fixture with one listed using water in similar quantities and at similar rates. The assigned loads for fixtures with both hot and cold water supplies are given for separate hot and cold water loads and for total load. The separate hot and cold water loads are three-fourths of the total load for the fixture in each case.
(From Nielson, L. 1981. *Standard Plumbing Engineerings Design,* 2nd ed. New York: McGraw-Hill.)

where h_f is the friction head loss in a section of pipe, K is a constant, and Q is the discharge.

The value of the exponent n depends on the governing equation selected for solving the problem. As an example, the Hazen-Williams equation (equation 25.20) can be written as

$$Q = 1.318C\left(\frac{D}{4}\right)^{0.63} S^{0.54}\left(\frac{\pi D^2}{4}\right) \quad (25.31)$$

For a given pipe of known material and diameter flowing full the equation simplifies to:

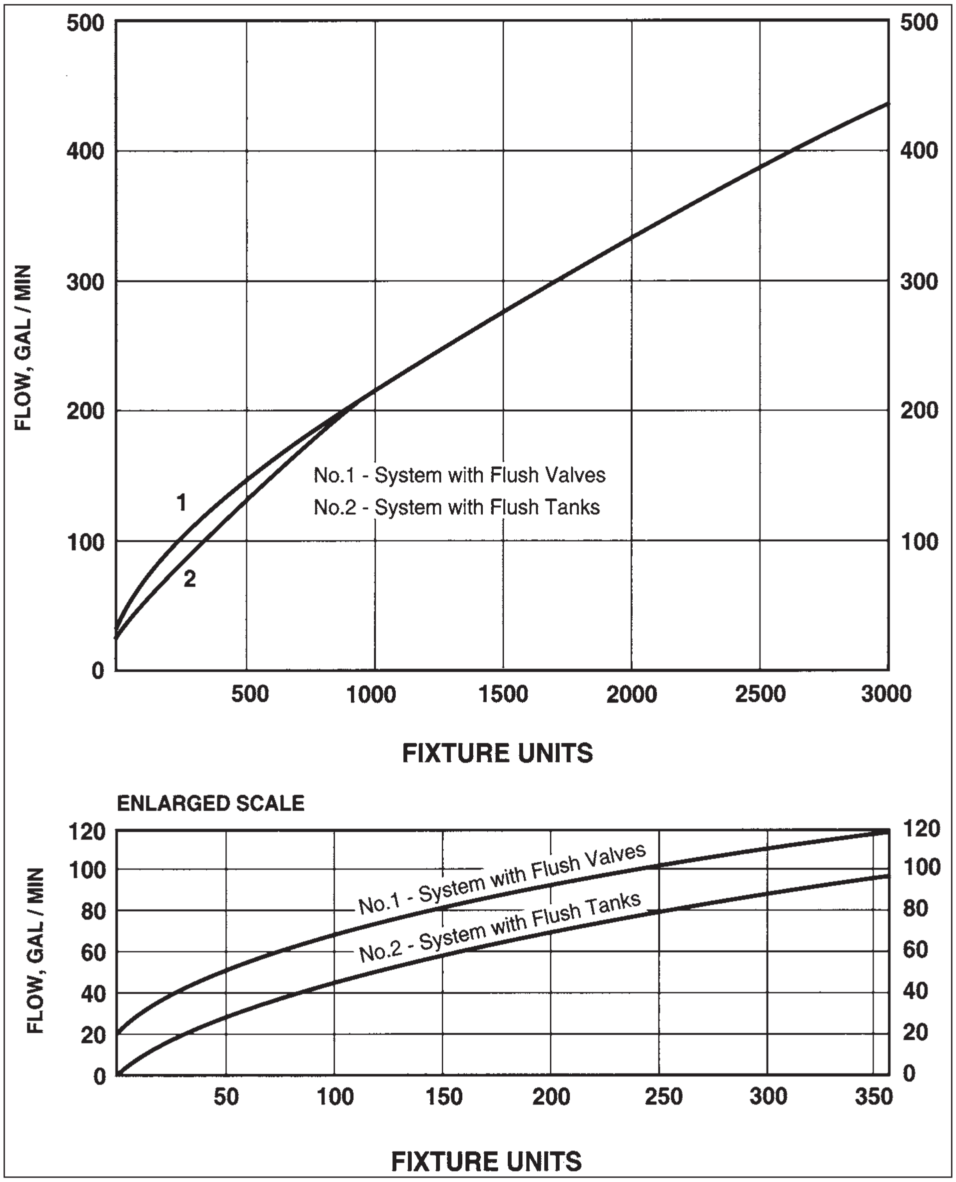


FIGURE 25.36 Curves for estimating demand load.

$$Q = KS^{0.54} \tag{25.32}$$

where the constant K incorporates the coefficient 1.318, the diameter, the C factor, n, and other constants. Substituting for S, the equation is:

$$h_f = KQ^{1.85} \tag{25.33}$$

There are two main underlying assumptions in the Hardy-Cross method. The first is that continuity must be preserved (the total flow into a junction equals the total flow exiting the junction). The second is that pressure at any junction is single valued (the summation of the head loss around a loop is zero).

With reference to Figure 25.38, if continuity is preserved, the flow at point B is equal to the flow at point C. For the pressure at point C to be single valued, the head loss in the upper loop must equal the head loss in the lower loop. In all likelihood the pipe lengths and diameters and possibly even the pipe material in each loop are different. The discharge will divide at point B in such a way that the head loss through the two sections of loop is equal. As a result, if a clockwise direction of flow is assumed to be positive, the summation of the head loss from BC_{up} around CB_{low} will be zero.

The solution is determined through a series of iterations, with each iteration producing a loop correction factor. Some value of flow for Q_{up} and Q_{low} is assumed. For these assumed flows, if $h_{f(BC\text{-up})}$ is greater than $h_{f(BC\text{-low})}$, then the discharge in the upper loop must be reduced and the discharge in the lower loop must be increased. That is, $Q'_{up} = Q_{up} + \Delta Q$ and $Q'_{low} = Q_{low} - \Delta Q$, where ΔQ is the loop correction factor.

TABLE 25.15 Fixture Unit Count for Example Problem

FIXTURE	TOTAL UNITS	WSFU	TOTAL WSFU
Kitchen sink	15	2	30
Dishwasher	15	1	15
Lavatory (sink)	15	1	15
Water closet (flush tank)	15	3	45
Bathtub	15	2	30
Laundry machine	4	4	16
			Total = 151

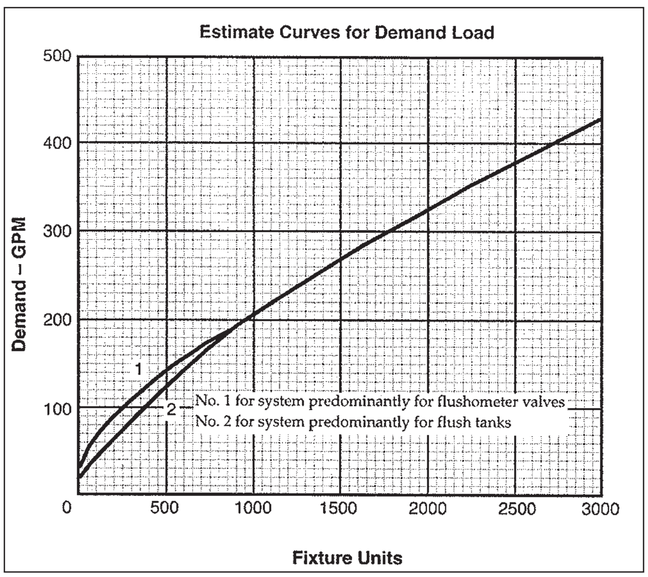
Eventually the discharges in each loop are adjusted so that the summation of the head loss around the loop converges to zero. The flow correction factor for the loop is:

$$\Delta Q = \frac{h_{f\,\text{BD-up}} - h_{f\,\text{BC-low}}}{1.85\left(\dfrac{h_{f\text{BC-up}}}{Q_{\text{up}}} + \dfrac{h_{f\text{BC-low}}}{Q_{\text{low}}}\right)} \tag{25.34}$$

For a more complex multiloop problem, the initial task is to set up the following parameters for the pipe system:

- Pipe sizes
- Pipe lengths and materials
- All locations of flows entering and leaving the system
- A sign convention for the direction of flow

In the initial assumption of pipe flows, it is imperative for the sum of the flows at any junction to be zero. Using



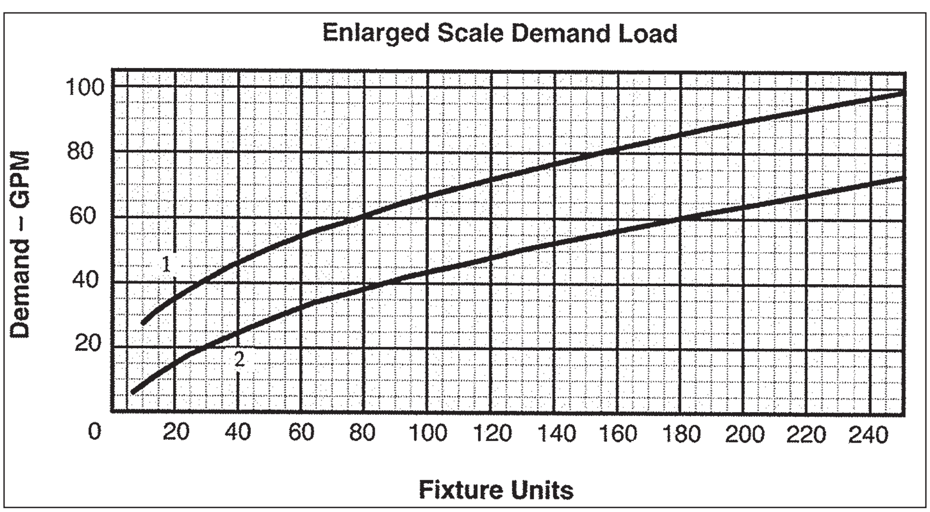


FIGURE 25.37 Chart for determination of flow in pipes. (Reprinted with the permission of the International Association of Plumbing and Mechanical Officials)

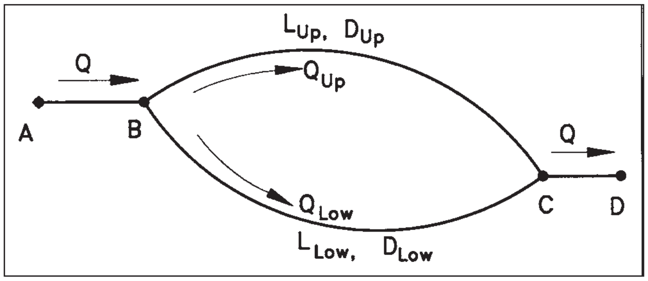


FIGURE 25.38 Simple loop for Hardy-Cross solution.

these initial conditions, the head loss for each pipe is computed as:

$$\Delta Q = -\left(\sum_{i=1}^{n} (H_f)_i\right) \times \sum_{i=1}^{n}\left(\left|\frac{(H_f)_i}{Q_i}\right|\right) \qquad (25.35)$$

where $(H_f)_i$ represents the head loss in the ith pipe of the loop and Q_i is the discharge in that pipe, which was used to calculate H_f.

The sign convention applies to the H_f term—all flows in the negative direction will have negative H_f terms.

Figure 25.39 shows a simple three-loop system with pipe information and assumed flows. Table 25.16 summarizes the information shown on Figure 25.39. Note the algebraic sign attached to the discharge: negative if the flow is counterclockwise, positive for clockwise direction. At each junction the $\Sigma Q = 0$. In most systems there are valves, pumps, storage tanks, and other components that impact the calculations. Additionally, systems are analyzed for maximum fire flow demands at several locations to ensure adequate pressures everywhere. This simple system serves only to illustrate the fundamental procedure for Hardy-Cross calculations.

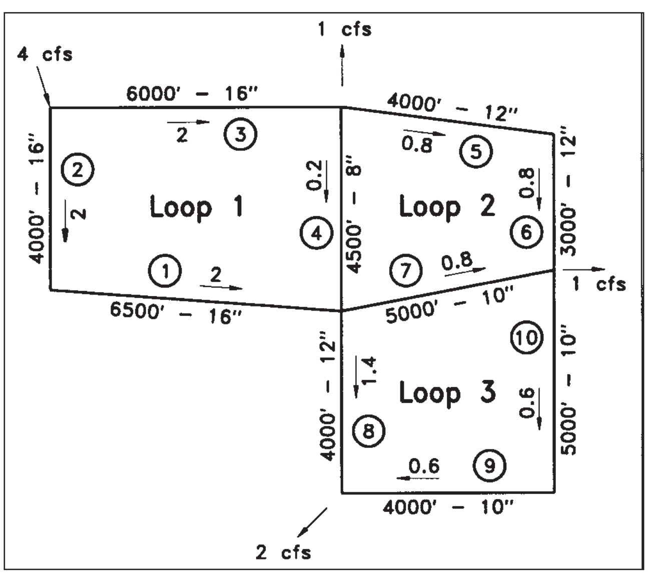


FIGURE 25.39 Schematic diagram for Hardy-Cross example.

TABLE 25.16 Initial Assumptions for Flows and Directions

INPUT VALUES

Loop No.	Pipe No.	Diameter (in.)	Length (ft)	Q (cfs)
1	1	16	6500	–2.00
	2	16	4000	–2.00
	3	16	6000	2.00
	4	8	4500	.20
2	4	8	4500	–.20
	5	12	4000	.80
	6	12	3000	.80
	7	10	5000	–.80
3	7	10	5000	.80
	8	12	4000	–1.40
	9	10	4000	.60
	10	10	5000	.60

Tables 25.17 and 25.18 show how loop flows are adjusted by a ΔQ correction. Note how the adjustments are determined for pipes common to more than one loop. For example, pipe 4 is common to loops 1 and 2. In loop 1, the first iteration ΔQ is +0.082, while the ΔQ for loop 2 is 0.113. The new flow in pipe 4 is then 0.20 + 0.82 − 0.113 = 0.17 cfs. The initial flow of 0.2 is adjusted simultaneously by the correction of the first loop and the negative of the correction of the second loop. The iterative process continues until the sum of the absolute values of the ΔQ's is less than a prescribed minimum tolerance. The acceptable tolerance depends on the precision of the known values and the degree of accuracy required.

DISTRIBUTION SYSTEM CONSTRUCTION PLANS

Preliminary Layout and System Modeling

Waterline analysis and design are done using computers and commercial software, such as KYPIPE, CYBERNET, WaterCAD, and others. To model the system accurately, data is needed on pipe geometry, system demand, flow, and pressure for the existing water services at the points where the proposed waterline connects to the existing waterline. Pressure and flows at these connection points serve as the boundary conditions for the proposed waterline. Additionally, data may be needed on storage tank capacities, water surface elevations in the storage tank at the time of the flow tests, and pumping station and well pump curves.

TABLE 25.17 First Iteration Values

Loop No.	Pipe No.	Diameter (in.)	Length (ft)	Q (cfs)	H_L	$1.85*H_L/Q$	Q' (cfs)
1	1	16	6500	–2.00	–5.47	5.06	–1.92
	2	16	4000	–2.00	–3.37	3.11	–1.92
	3	16	6000	–2.00	5.05	4.67	2.08
	4	8	4500	.20	1.56	14.43	.17
					–2.23	27.27	
					$\Delta Q = -(-2.23/27.27) = .082$		
2	4	8	4500	–.20	–1.56	14.43	–.17
	5	12	4000	.80	2.51	5.80	.91
	6	12	3000	.80	1.88	4.34	.91
	7	10	5000	–.80	–7.61	17.60	–.52
					–4.78	42.17	
					$\Delta Q = -(-4.78/42.17) = 0.113$		
3	7	10	5000	.80	7.61	17.60	.52
	8	12	4000	–1.40	–7.06	9.33	–1.57
	9	10	4000	.60	3.57	11.00	.43
	10	10	5000	.60	4.47	51.71	.43
					8.59	51.73	
					$\Delta Q = -(8.59/51.73) = -0.166$		

If the data is not available directly from the utility company, flow tests will have to be conducted at nearby hydrants to obtain static and residual pressures for several different flow conditions. If the municipality or water utility company has the computational abilities and resources, they may dictate the location and size of the water supply system components. Some larger utilities now use system modeling software that is integrated with a geographic information system (GIS) for the management of their water infrastructure. For small systems, the consulting engineer will normally do the hydraulic analysis and design of the additional distribution system needed for the new development project.

The following criteria are considered when designing the water supply system:

- In most cases the flows in the water distribution system are designed to supply the amount of water needed to meet the maximum daily potable demand plus fire flows or the peak hour flow, whichever is greater (the AWWA defines the maximum daily demand as the maximum amount of water used during one 24-hour period occurring during the latest three-year period).
- The minimum residual pressure in the system at the average daily demand should be around 40 to 50 lb/in^2. According to the AWWA, the average daily demand is the average amount of water used each day during a one-year period for the entire system. If the water pressure in the main is 60 lb/in^2 or greater, the engineer should consider incorporating pressure-reducing valves on the domestic service lines.
- The minimum residual system pressure during the peak hour demand on the maximum day is typically required to be 30 lb/in^2 or greater. Additionally, the pressure in the water main should be greater than 20 lb/in^2 during the maximum daily demand plus fire flow.

The preceding considerations are only guidelines for designing the water distribution system. The regulating

TABLE 25.18 Second Iteration Values

Loop No.	Pipe No.	Diameter (in.)	Length (ft)	Q (cfs)	H_L	$1.85*H_L/Q$	Q' (cfs)
1	1	16	6500	–1.92	–5.07	4.89	–1.85
	2	16	4000	–1.92	–3.12	3.01	–1.85
	3	16	6000	2.08	5.44	4.84	2.15
	4	8	4500	.17	1.13	12.30	.26
					–1.62	25.04	
					$\Delta Q = -(-1.62/25.04) = 0.064$		
2	4	8	4500	–.17	–1.13	12.30	–.26
	5	12	4000	.91	3.20	6.51	.88
	6	12	3000	.91	2.40	4.88	.88
	7	10	5000	–.52	–3.43	12.20	–.57
					–1.04	35.89	
					$\Delta Q = -(1.04/35.89) = 0.029$		
3	7	10	5000	.52	3.43	12.20	.57
	8	12	4000	–1.57	–8.68	10.23	–1.55
	9	10	4000	.43	1.96	8.43	.45
	10	10	5000	.43	2.45	10.54	.45
					–0.84	41.40	
					$\Delta Q = -(-.84/41.40) = -0.20$		

authorities should be consulted for specific line pressures, demand flows, and other design criteria.

After estimating the demand and determining the peaking factors, lay out the pipe network, including fire hydrants, valves, tees, and crosses, on a plan view of the project. The layout also should include any stubouts needed to provide water service to future developments. In laying out the waterline, the engineer follows the local criteria for setting the waterline in public rights-of-way. Based on the number of dwelling units being served, the engineer estimates the pipe size and labels them on the plan view. In most moderately sized developments, pipe diameters typically range from 6 inches on short cul-de-sacs to 12 inches for the main feeder line. Typically, the size requirement results from fire flow demand and not because of the domestic demand. In all likelihood, the distribution lines through the proposed development will have sizes similar to the existing lines in surrounding similar developments.

Input this data into the model and examine the output for high velocities, excessive head losses, and unacceptable pressures. Adjust the pipe sizes to meet demand and local standards criteria. When the model analysis is complete, finish the plan and profile of the waterline for the construction drawings.

The Water Main Plan and Profile

The plan and profile of the waterline identifies the size and type of pipe and the location of the fittings. To the contractor, it shows the material needed, the volume of excavating, and potential construction problems. To the review agencies, the plan and profile shows that the waterline is in conformance with the applicable building and health codes.

The waterline location is accurately drawn on the plans as per local criteria. For stakeout and construction purposes, the location of a waterline is identified by stationing. Since most waterlines in a development project are located in the street and typically run near parallel with the centerline, the street stationing can be used for stationing the waterline. When the course of a waterline cannot be tied to the street, an arbitrary stationing system on the waterline itself serves the same pur-

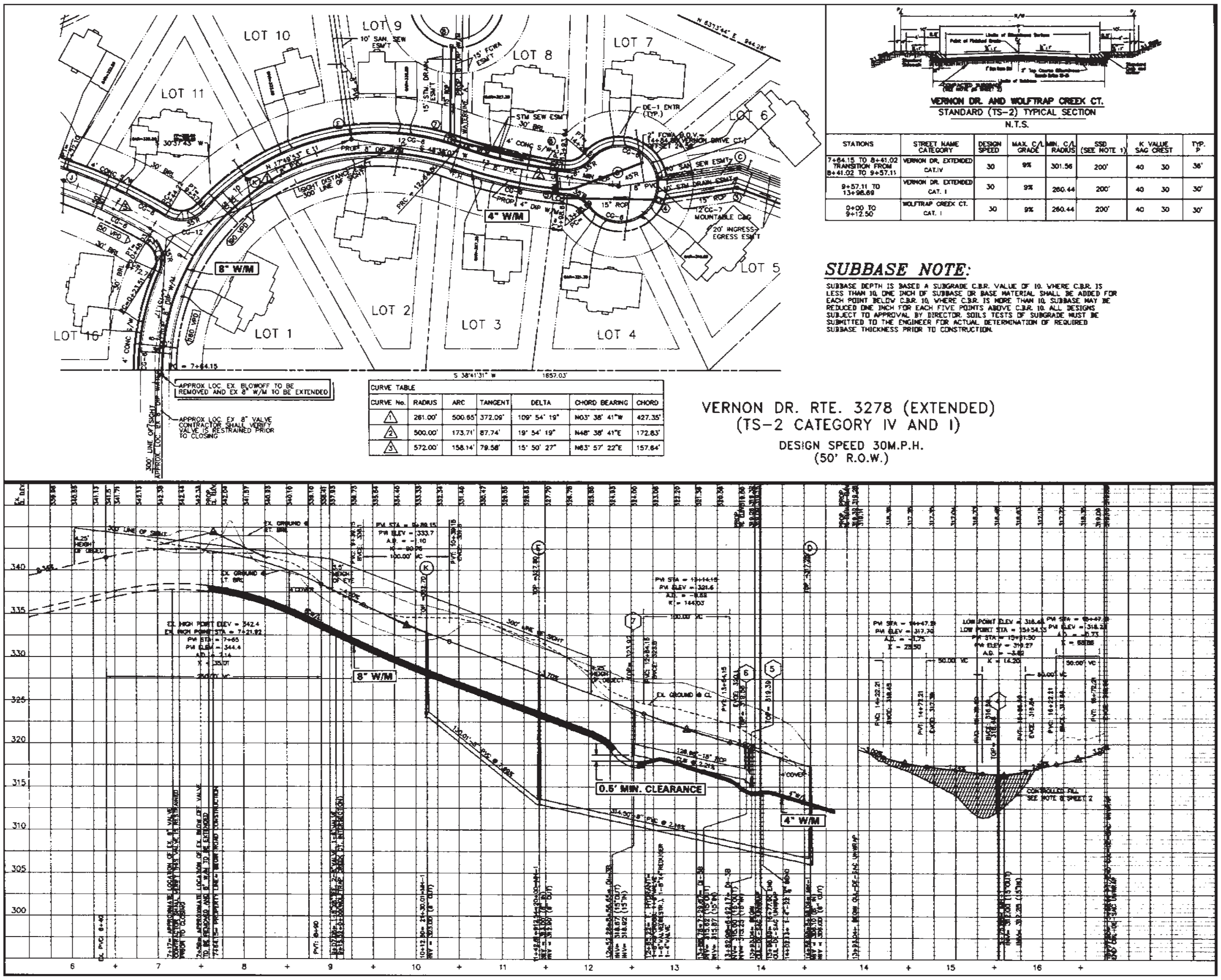


Figure 25.40 Plan and profile view of a typical waterline.

pose. Although stationing of the pipe system is done as a matter of convenience and should reasonably reflect the length of the pipe used, it does not need to start with 0 + 00. In the figures showing the plan and profile of a typical waterline, the waterline stationing coincides with the street stationing.

Although some localities allow pipes to be laid with curves, other standards require that pipe direction changes be made with elbow fittings. On commercial sites, the designer needs to know where the fire hose connections at the building are located. In addition, some locales have minimum spacing for fire hydrants in commercial areas. Both of these items affect the placement of the hydrants. In residential areas, placement of fire hydrants may be based on minimum spacing or based on the area of coverage for the required fire flow. The engineer should ensure that the location of the hydrants shown on the worksheet complies with appropriate design criteria. After the waterline location and stationing are established in the plan view, the waterline profile is drawn using the same stationing system. In the profile view, pipe characteristics (e.g., diameter, material, and bearing strength) are labeled. The profile view identifies the station of fitting, hydrants, and other pertinent components. The profiled waterline shows how it will weave around other utilities. As discussed previously, special construction techniques may be necessary when the waterline is placed either near a sanitary sewer or at less than minimum depth. The engineer should ensure that all utility crossings are shown in the profile view and that minimum clearance (as per applicable standards) is maintained.

At the point where the proposed waterline connects to the existing water main, the plans should identify the method for location of existing line and type of connection (e.g., wet tap with tapping sleeve and valve). Although the water utility company probably has records to show where the existing line should be, test holes are dug to find the exact location. In many instances, where the waterline is terminated from a prior development, a blowoff valve is set to easily connect a future waterline (see Figure 25.40).

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CHAPTER 26

DRY UTILITY DESIGN AND ENGINEERING

Cash E. Davidson, PE, RCDD, LEED AP

INTRODUCTION

For many years developers have been pitching the advantages of underground utilities versus aerial. What started as a differentiator to improve sales has developed into an expectation among residential consumers. In fact, some municipalities have passed local laws that require all power and communication utilities to be underground within residential developments. There are sound reasons for this trend beyond the obvious aesthetic improvement. Underground utilities within residential developments are generally direct buried, improving their cost competitiveness over aerial. They are safe from high winds and ice and, therefore, much less susceptible to weather-related outages. They are less susceptible to vandalism or sabotage. Conversely, underground utilities are more likely than aerial to be accidentally damaged during construction. Also, when damage or failure occurs, it is more time consuming to locate the problem and more expensive to repair.

For the site's civil engineer, communication and coordination are the key to successful dry utility design. The site engineers are often the link between the building engineers, the utility companies, and local municipalities. These utilities have requirements for clearance, bend radius, and burial depth that are very different from gravity or pressure utilities, but they also offer unique opportunities. Dry utilities can be offset over, under, and around conflicts; they have much more flexibility with burial depth and are generally much easier to locate once placed underground. Understanding the design requirements of these utilities allows the site engineer to effectively plan the integration of these systems into a project and provides a better overall site design.

Underground dry utilities are generally comprised of electrical power and communications infrastructure. Electrical power is typically in the form of low-voltage and/or medium-voltage installations. Communications infrastructure includes voice, data, and video services transmitted over copper and fiberoptic cabling. Each category of power and communications infrastructure has its unique requirements for installation, access, and separation from other utilities. These requirements can differ from one service provider to the other or from one area of the country to the next. Proper design and coordination of underground dry utilities begin with a conceptual understanding of the project's needs in terms of power, system voltage, and communications connectivity. This rough data is conveyed to the various service providers that will deliver power, phone, data, and video to the site. The service providers will share with the designer the available infrastructure and their particular installation requirements. Armed with this information, the designer can then proceed with detailed engineering.

UNDERGROUND ELECTRICAL UTILITIES

Electrical power generally consists of low-voltage and medium-voltage installations. Low voltage is typically used for the main service into a building, for branch circuits, and for site lighting. Medium voltage is typically used for distributing power over a long distance and for the main service to large industrial manufacturing facilities. Common system voltages for these two categories are listed in Table 26.1. Low voltage includes systems up to 600 V, while medium voltage includes systems between 600 V and 36 kV. Voltages above 36 kV are considered high-voltage systems and are beyond the scope of this text.

TABLE 26.1 Common Electric Systems on Land Development Projects

Common Low-Voltage Systems	Common Medium-Voltage Systems
120/240 V	2400/4160 V aka: 5 kV
120/208 V	7200/12470 V aka: 15 kV
277/480 V	13.2/22.9 kV aka: 25 kV
	19.9/34.5 kV aka: 35 kV

Ductbank Design

Electrical power is typically distributed underground via direct buried cables, direct buried conduits, or cast-in-place, concrete-encased conduits called *ductbank*. Protection increases from cable to conduit to ductbank but so does cost. Direct buried cables are typically used in residential developments for their ease of installation and cost savings. Direct buried conduits are typically used in areas that would be difficult to excavate in the future—under roads, sidewalks, and structures. When added physical protection is required or when minimum direct bury depth is not obtainable, ductbank is used. Ductbank offers the flexibility of planning for future growth and replacing or upgrading cabling without further excavation. It is commonly used in public rights-of-way and in campus environments. This discussion focuses primarily on ductbank design, but many of the design principles are applicable to direct buried cables and conduits.

The purpose of the concrete-encased ductbank is to provide physical protection against future excavation and to add structural strength to the conduits (ducts) should the soil below settle or be undermined (see Figure 26.1). PVC conduits are generally used in ductbank in lieu of metal conduits for several reasons: ease of installation, lower cost, and corrosion resistance. The keys to good ductbank design include steel reinforcing bars (rebar) and spacing between the conduits. Steel #4 rebar should be installed along the entire length of the ductbank—a minimum of one in each corner with #4 stirrups installed every 5 feet. PVC conduits are tied to the steel reinforcing to prevent "floating" when the concrete is poured. Spacing the conduits allows concrete to settle between the conduits and results in a much stronger system. Figure 26.2 shows duct spacers used in a ductbank. Spacers are generally installed every 5 feet along the conduit run. Couplings should be staggered 12 inches apart to prevent a weak spot in the ductbank. The National Electrical Code (NEC, NFPA 70) requires a minimum of 3-inch separation between conduits and a minimum of 2 inches of concrete cover. Figure 26.3 shows a typical ductbank detail with dimensions. Figure 26.4 illustrates the installation of direct buried conduits. Direct buried cables and conduits are laid on a 3-inch bed of sand and then covered with 3 inches of sand to prevent damage to cables or conduits.

Typical Section. The conduit arrangement within the ductbank varies to suit site conditions, but generally the goal is to create a square or near square geometry. A square shape uses the concrete and reinforcing materials efficiently and costs less to excavate. If trench sides are adequately firm, they may be used as forms for the ductbank. In sandy or unstable soil, wood forms must be used. Duct sizes range from as small as 1 inch for site lighting to as much as 6 inches for power feeders. Duct size is dependent on conductor fill, number of bends, and pulling distance. Generally, ducts are never filled more than 40 percent. Duct sizing calculations are usually performed by the building electrical engineer or the utility provider and are beyond the scope of this text. It is considered good design practice to provide a minimum of 25 percent of the ducts as spare for future use. Many utility companies require 50 percent spare.

Horizontal and Vertical Layout. The ductbank system should be designed using bends with the least curvature possible while avoiding abrupt direction changes. Schedule 40 PVC is sufficiently flexible to allow minor changes in direction or elevation without the use of factory-made fittings. Where possible, lay out the ductbank system both horizontally and vertically with minimum 25-foot radius

FIGURE 26.1 Ductbank photo.

FIGURE 26.2 Duct spacers.

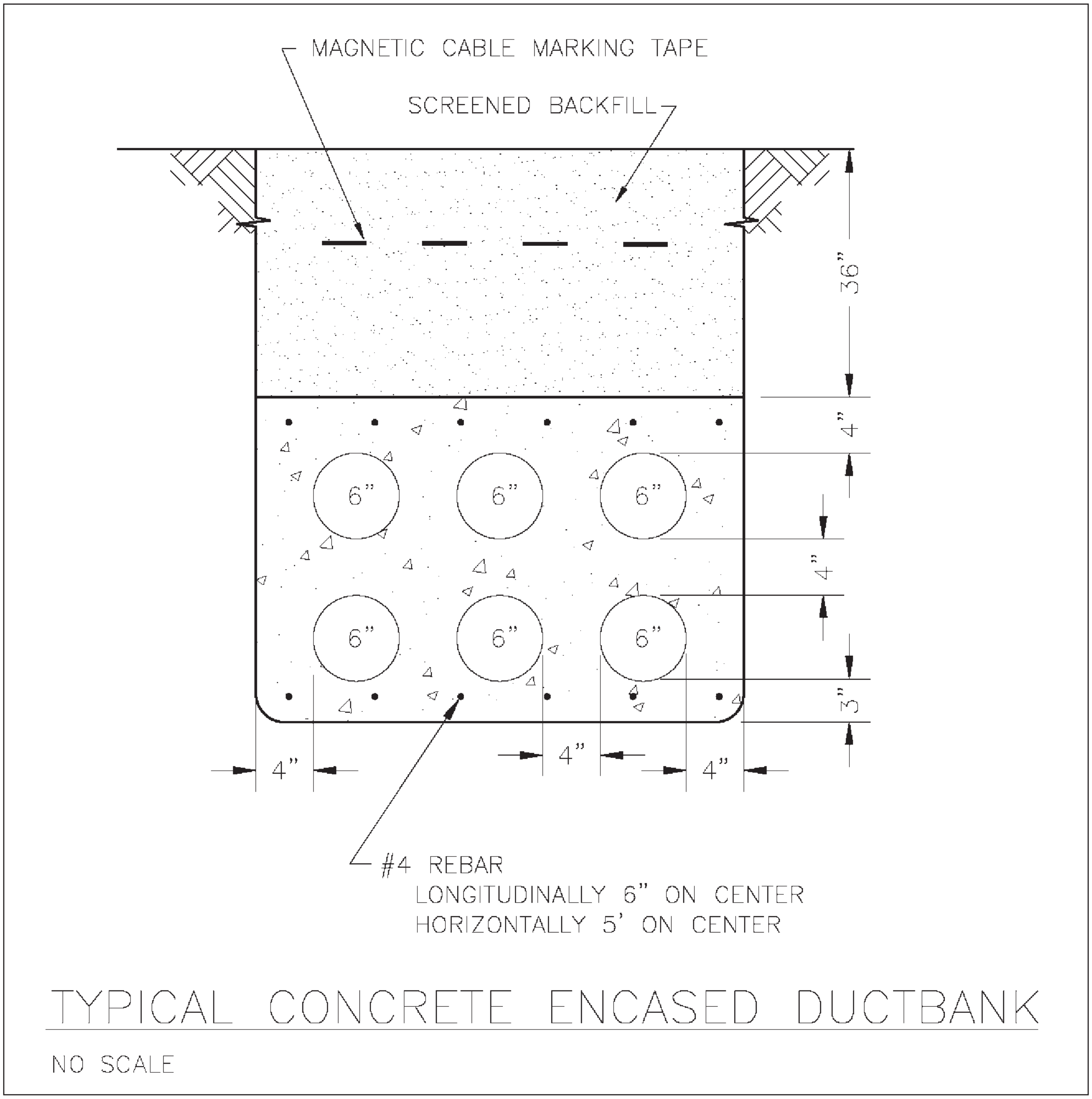


FIGURE 26.3 Typical ductbank detail.

bends. Where an abrupt direction change is required, use factory-produced fittings with a minimum bend radius of 48 inches. Bend radii between 48 inches and 25 feet can be accomplished in the field using a hot box (see Figure 26.5).

To prevent water accumulation, conduits and ductbanks are sloped to drain at a minimum of 3 inches per 100 feet or 0.25 percent. Conduits should always be sloped toward manholes and away from buildings.

Transposition. There are times when the geometry of the ductbank must be altered along its route to avoid obstacles and to facilitate entry into a structure. For example, a 12-way ductbank of 4-inch ducts will usually be arranged in three rows of four ducts that can be approximately 29-inch width by 22-inch height. When crossing a waterline buried at 36 inches, the ductbank must maintain 6 inches of cover and 12 inches of separation from the waterline. Therefore, the ductbank can pass below and require 70 inches of excavation, or it can transition to two rows of six ducts, pass above, and require only 24 inches of excavation. Similar situations arise when entering manholes and buildings. Often entry points require the ductbank to transition to a vertical rectangle that is only two or three rows wide.

Burial Depth and Proximity to Other Utilities. Burial depth of electrical conduits depends on whether they are concrete-encased and where they are routed. Concrete-encased conduits may generally be buried at shallower depths than

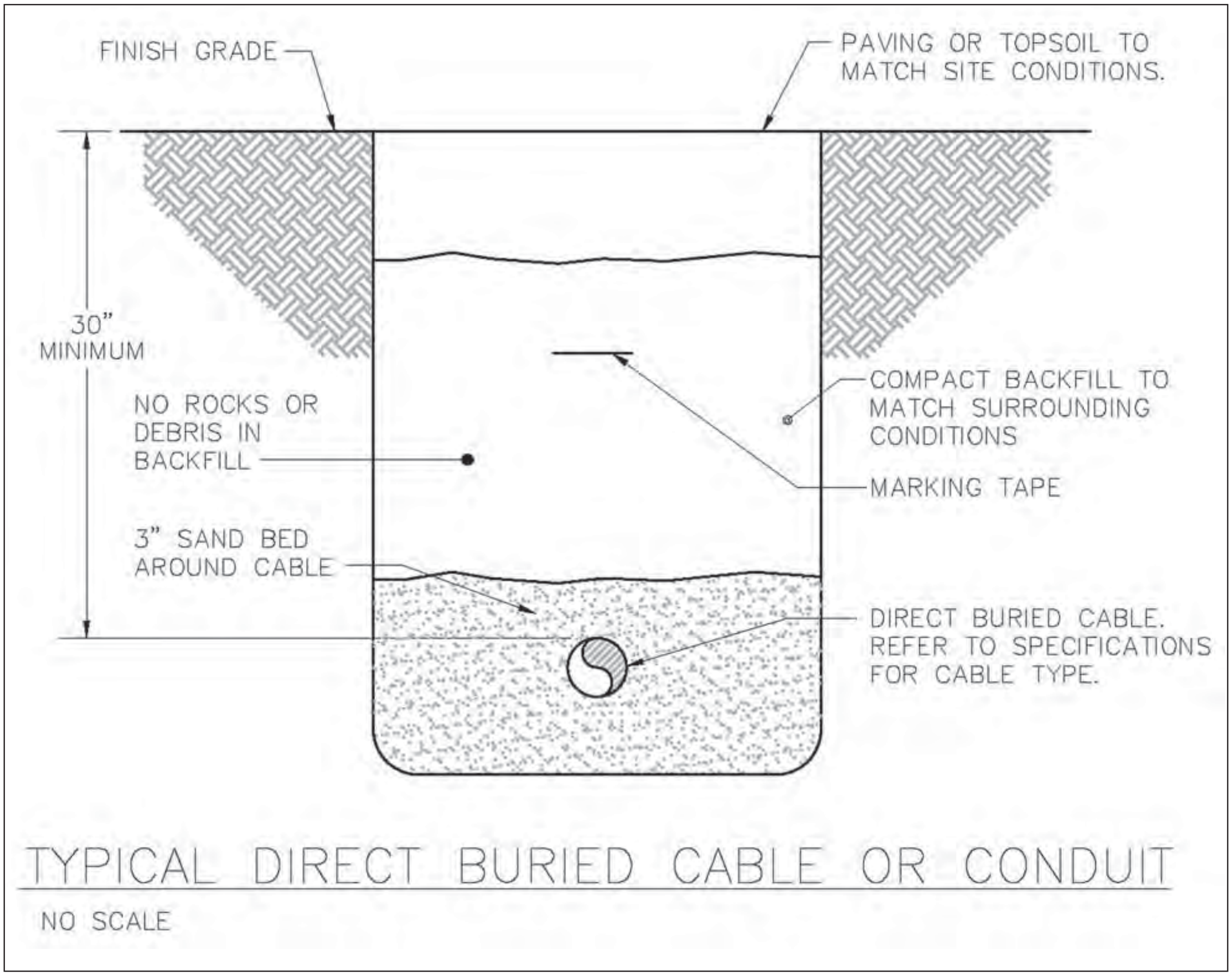


FIGURE 26.4 Direct buried conduit installation.

nonencased conduits regardless of routing, and conduits routed under roadways generally are buried deeper than conduits located beside a road. Table 26.2 indicates burial depths dictated by the NEC.

When considering separation from other utilities, access and heat are the major concerns. Ductbanks should maintain a minimum of 12-inch separation (horizontal and vertical) from other utilities such as waterlines, sewer lines, and gas to allow adequate access to repair these lines should a break occur. When routing in the proximity of steam lines, a 24-inch minimum separation is required to avoid thermal damage to the conductors within the ductbank. When crossing steam lines, always route ductbanks below rather than above the steam lines. Where adequate separation from steam is not possible, a suitable thermal barrier must be used such as 6 inches to 12 inches of rigid or expanding foam insulation. When utilities cross, each utility must be self-supported so as not to transfer load from one to the other.

Manhole Design

Manholes serve several purposes within the electrical distribution system: they provide access to the conductors, they provide a location for splices, they provide pulling points along the ductbank route, and they allow changes in direction. A well-designed manhole must provide:

- Access cover
- Access ladder
- Grounding for safety
- Racking provisions to support cables
- Pulling irons to facilitate cable installation
- Drainage or sump pump
- Structural integrity for vehicle traffic if applicable
- Knockout panels for conduit entry
- Working space for cable installation and maintenance

Figure 26.6 shows typical square and octagonal manholes. Octagonal manholes are more costly but have the advantage of more easily racking cables (see Figure 26.7). Since the cables enter the octagonal manhole at the corner, only two

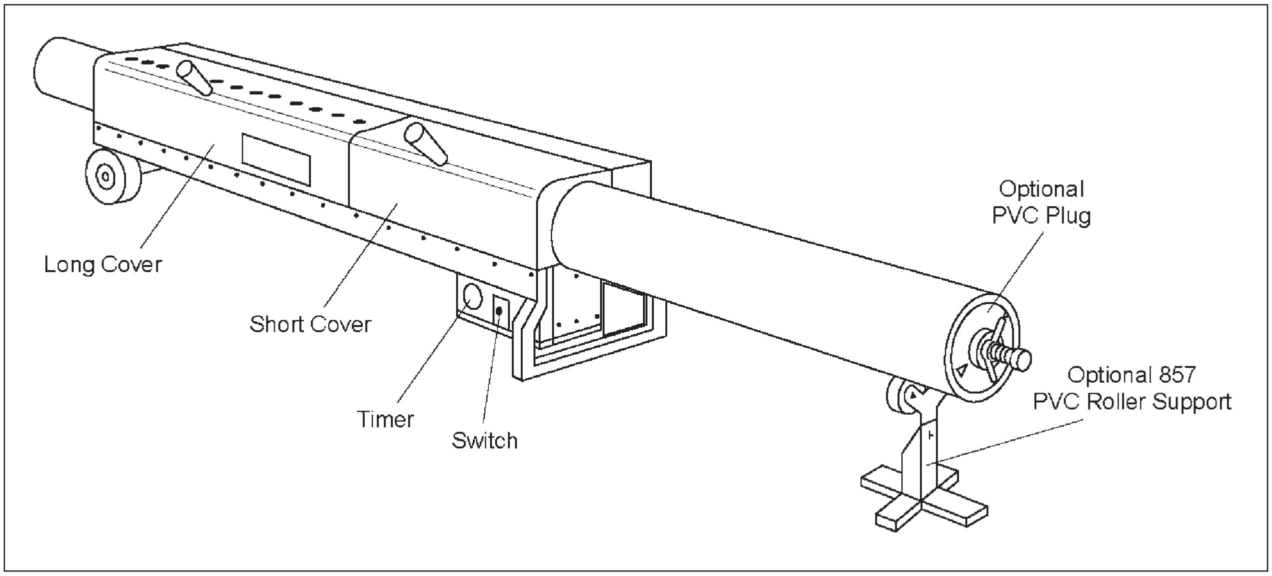


Figure 26.5 Hot box. (Greenlee Textron © 2000)

45-degree bends and one 90-degree bend are required to exit the opposite corner as the cables are racked around the perimeter. The same situation requires four 90-degree bends in a square (or rectangular) manhole. There are some situations where site constraints require a cast-in-place manhole, but most are precast to the engineer's specifications. To help standardize precasting and reduce costs, the precaster provides knockout panels for conduit entry. Knockouts are very thin, unreinforced panels in the sides of the manhole that give the contractor some flexibility (vertically and horizontally) with the entry point into the manhole. These knockouts also facilitate future conduit entries should they be necessary.

Manhole Spacing. Manholes should be laid out along the ductbank route based on the maximum run, or pulling distance, of the cable to be installed and at all major changes in direction. The pulling distance is usually specified by the building engineer or the utility and varies depending on the type of cable, the percent fill of the conduit, the number of bends, and the size of the manholes. Minor vertical and horizontal bends can occur between the manholes, but these bends reduce the maximum pulling distance and should be accounted for in the system design.

Electrical Equipment

Eventually the electrical power conductors terminate at a piece of electrical equipment. This could be a medium-voltage transformer, a medium-voltage switch, an electrical meter, or switchgear located within a building. Placement, access, and working clearances for this equipment are dictated by the NEC, the NESC, and the local utility. The generally accepted standard for clearance of medium-voltage equipment is to maintain 10 feet from any building opening (doors, windows, or louvers), 3 feet on all nonoperable sides, and 10 feet on all operable sides. Operable sides are sides that have doors for access to components within the equipment enclosure. The 10-foot clearance is required to allow the use of a hotstick, a long insulated pole used to operate medium-voltage equipment while energized, or hot. The local utility can provide the dimensions of the medium-voltage transformer or switch to be used, but most will fit on a 10-foot by 10-foot concrete pad. To conservatively estimate the required space and clearances, designers assume a 10-foot by 10-foot pad and lay out clearances from it, knowing the actual equipment will be smaller. Often it is desirable or even required to screen electrical equipment from view; however, it is important that bollards, shrubs, fences, parking spaces, and other obstructions remain outside of the required clearances. It is also important to provide access for a flatbed boom truck to allow removal and replacement of the equipment. Electrical equipment space and access considerations are based on public health and safety measures; thus, it is important to work closely with the utility provider and the authority having jurisdiction to balance the technical system needs with the site aesthetics. (See Figure 26.8.)

Low-voltage equipment clearances are based on the system voltage to ground and the physical surroundings or context in which the equipment is placed. This generally applies to meter bases, disconnect switches, panelboards, and switchboards. The system voltage to ground is the lower of the two numbers in any given cell within the table included in Figure 26.9. The context defines what is behind a person as he or she faces the equipment: is it insulated, grounded, or energized? This is best illustrated by Figure 26.9. In brief, if the system voltage to ground is 150 V or less, a 3-foot clearance is required regardless of the context. If the system voltage exceeds 150 V to ground, the clearance requirement grows from 3 feet to 4 feet depending on the context.

TABLE 26.2 Recommended Burial Depths

MINIMUM COVER* REQUIREMENTS, 0 TO 600 VOLTS, NOMINAL, BURIAL IN MILLIMETERS (INCHES)

Location of Wiring Method or Circuit	Type of Wiring Method or Circuit[‖,§]: Direct Burial Cables or Conductors[‡]		Rigid Metal Conduit or Intermediate Metal Conduit		Nonmetallic Raceways Listed for Direct Burial[†] Without Concrete Encasement or Other Approved Raceways		Residential Branch Circuits Rated 120 Volts or Less with GFCI Protection and Maximum Overcurrent Protection of 20 Amperes		Circuits for Control of Irrigation and Landscape Lighting Limited to Not More Than 30 Volts and Installed with Type UF or Other Identified Cable or Raceway	
	MM	IN	MM	IN	MM	IN	MM	IN	MM	IN
All locations not specified below	600	24	150	6	450	18	300	12	150	6
In trench below 50-mm (2-in) thick concrete or equivalent	450	18	150	6	300	12	150	6	150	6
Under a building	0 (in raceway only)	0	0	0	0	0	0 (in raceway only)	0	0 (in raceway only)	0
Under minimum of 102-mm (4-in.) thick concrete exterior slab with no vehicular traffic and the slab extending not less than 152 mm (6 in) beyond the underground installation	450	18	100	4	100	4	150 (direct burial) 100 (in raceway)	6 4	150	6
Under streets, highways, roads, alleys, driveways, and parking lots	600	24	600	24	600	24	600	24	600	24
One- and two-family dwelling driveways and outdoor parking areas, and used only for dwelling-related purposes	450	18	450	18	450	18	300	12	450	18
In or under airport runways, including adjacent areas where trespassing is prohibited	450	18	450	18	450	18	450	18	450	18

*Cover is defined as the shortest distance in millimeters (inches) measured between a point on the top surface of any direct buried conductor, cable, conduit, or other raceway and the top surface of finished grade, concrete, or similar cover.

[†]Raceways approved for burial only where concrete encasement shall require concrete envelope not less than 50 mm (2 in) thick.

[‡]Lesser depths shall be permitted where cables and conductors rise for terminations or splices or where access is otherwise required.

[‖]Where one of the listed wiring method types is used for one of the listed circuit types, the shallowest depth of burial shall be permitted.

[§]Where solid rock prevents compliance with the cover depths specified in this table, the wiring shall be installed in metal or nonmetallic raceway permitted for direct burial. The raceways shall be covered by a minimum of 50 mm (2 in) of concrete extending down to rock.

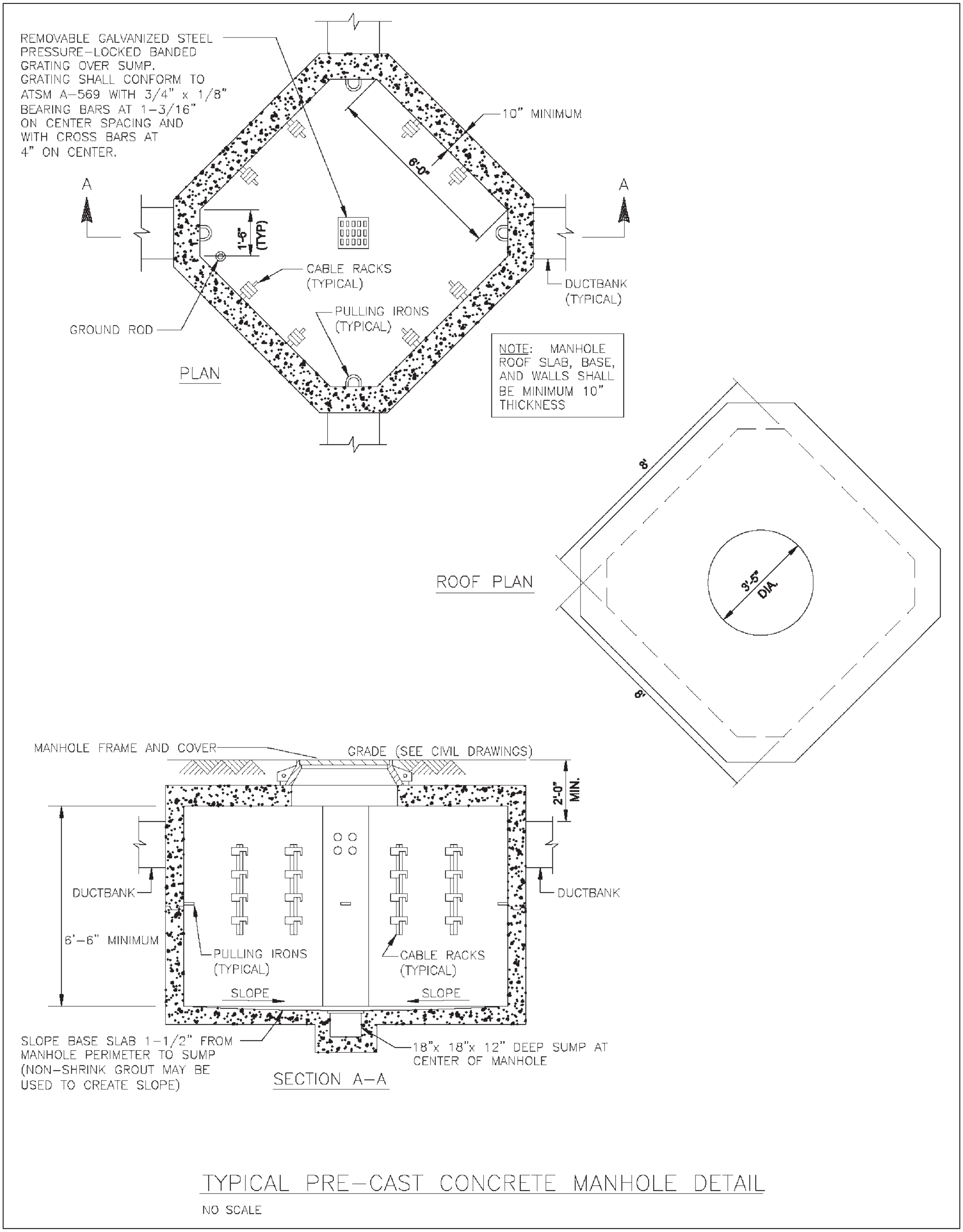


FIGURE 26.6 Electrical manhole details.

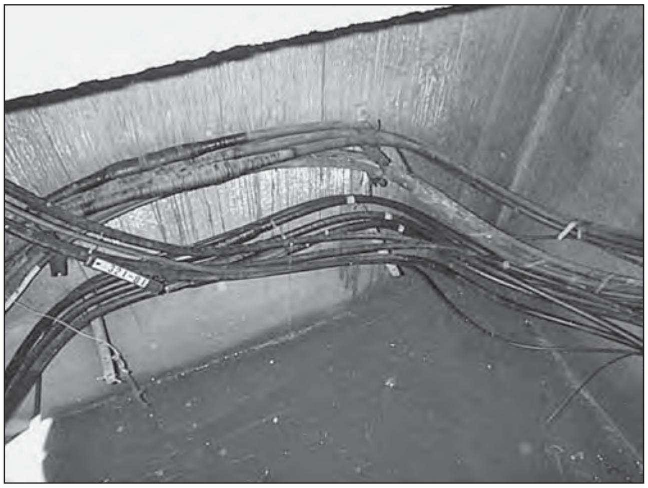


FIGURE 26.7 Typical racking arrangement on interior manhole wall.

Service Coordination

Close coordination between the designer and the local utility company is very important for a successful project. The utility company needs a clear understanding of the project and its characteristics, and the designer needs a clear understanding of the utility company's standards and requirements. Information the local utility company may request includes:

- A connected load summary showing lighting load, receptacle load, motor load, and the largest single motor.
- A site plan showing building footprint, public roads, parking areas, and proposed transformer and meter locations.
- A project schedule indicating construction start date and permanent power required date.
- Electrical load information that is typically provided by the building architect or the electrical engineer. The largest motor is usually associated with the building air-conditioning.

Information the designer should gather from the utility includes:

- System voltages available to the site
- Distance to nearest utility
- Cost, if any, to extend service to site
- Schedule when service can be provided
- Service and transformer installation requirements
- Dimensions of transformer and equipment pad
- Meter location and type
- Site plan approval showing transformer location, manhole locations, and routing of primary conductors to the transformer as well as secondary conductors to the building(s)
- Division of work between contractor and utility company

Service and transformer installation requirements often include service conduit size and quantity (including spares), burial depth, and encasement requirements. Defining division of work is very important. Some utilities provide and install all conduit and wire up to the meter; others require the contractor to provide and install only the conduit; and others require the contractor to provide and install all conduit and wire.

Much discussion and coordination generally surrounds the meter location. Owners and architects generally want the meter located out of sight, while the utility requires ready access for periodic reading. Residential meters are normally located on the side or rear of the structure outside of any fencing. Multitenant and commercial meters are normally grouped, or *ganged*, at one location and served by a single utility service. Industrial and institutional customers often have metering located at the pad-mounted transformer that serves the facility.

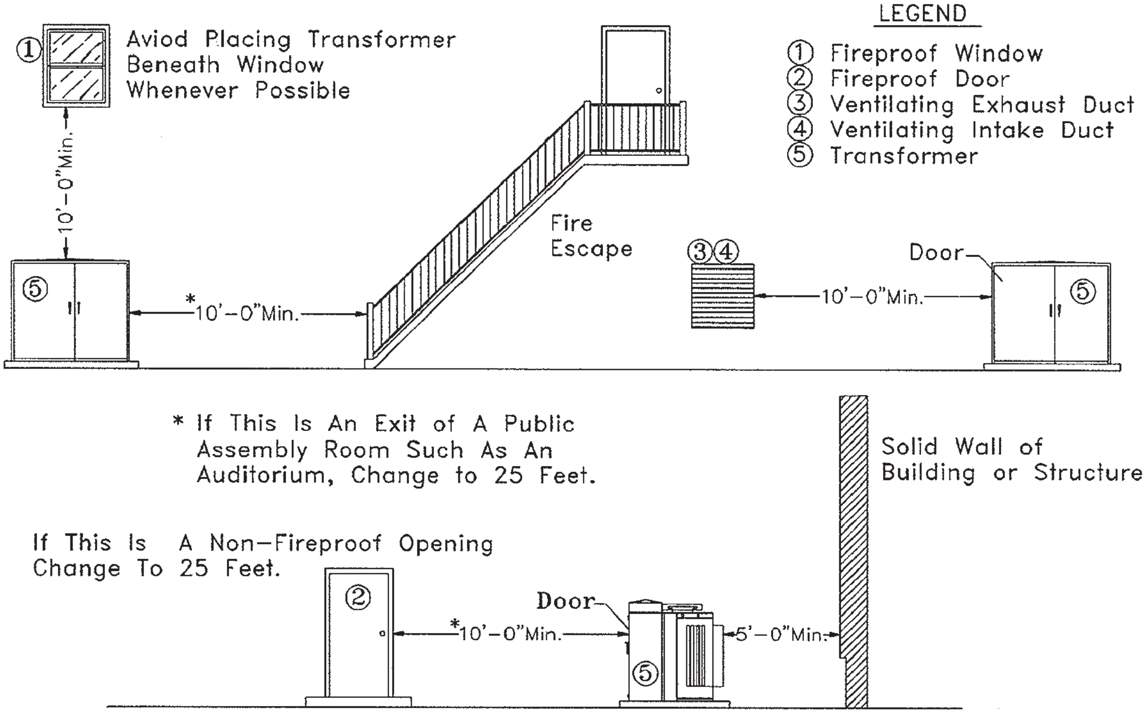
Deliverables

Construction documents in the form of drawings and specifications must convey the scope of the work and also the division of work between the contractor and the utility company. Most construction documents include:

- Overall site plan
- Existing location of power utility
- Routing of primary conductors to transformer
- Transformer location
- Routing of secondary conductors to building
- Equipment pad details
- Ductbank sections for each unique ductbank
- Manhole locations
- Manhole details and sections
- Ductbank profiles
- Location of any known crossings of existing utilities

See Figure 26.10 for site plan example.

Site (Exterior) Lighting Design. Site lighting design is often a critical component of the overall project design: it is provided first and foremost to ensure the comfort and safety of users and has secondary value in terms of aesthetics or decoration and often marketing that must also be considered. In developing a lighting plan, the key is to balance project lighting requirements with energy efficiency and light pollution minimization.



NOTES:

1. THE PRECEDING ARE MINIMUM CLEARANCES BETWEEN THE TRANSFORMER AND WINDOWS, DOORS, FIRE ESCAPES, ENTRANCES AND VENTILATING DUCTS.

2. PLACE TRANSFORMER SO THAT DOOR FACES AWAY FROM WALLS, FENCES, OR OTHER FIXED STRUCTURES. ACCESS REQUIRED FOR OPERATING LBTs WITH 8 FOOT HOT STICK HELD HORIZONTALLY.

3. NO BUSHES, TREES, OR OTHER OBSTRUCTIONS SHALL BE PLANTED OR INSTALLED IN FRONT OF TRANSFORMER DOORS.

4. NO OPENINGS IN BUILDINGS OR STRUCTURE WILL BE PERMITTED WITHIN 10 FEET OF TRANSFORMER. BUILDING MATERIAL, INCLUDING DOOR AND WINDOWS LESS THAN 25 FEET FROM TRANSFORMER SHALL BE FIREPROOF IN ACCORDANCE WITH NATIONAL FIRE CODE.

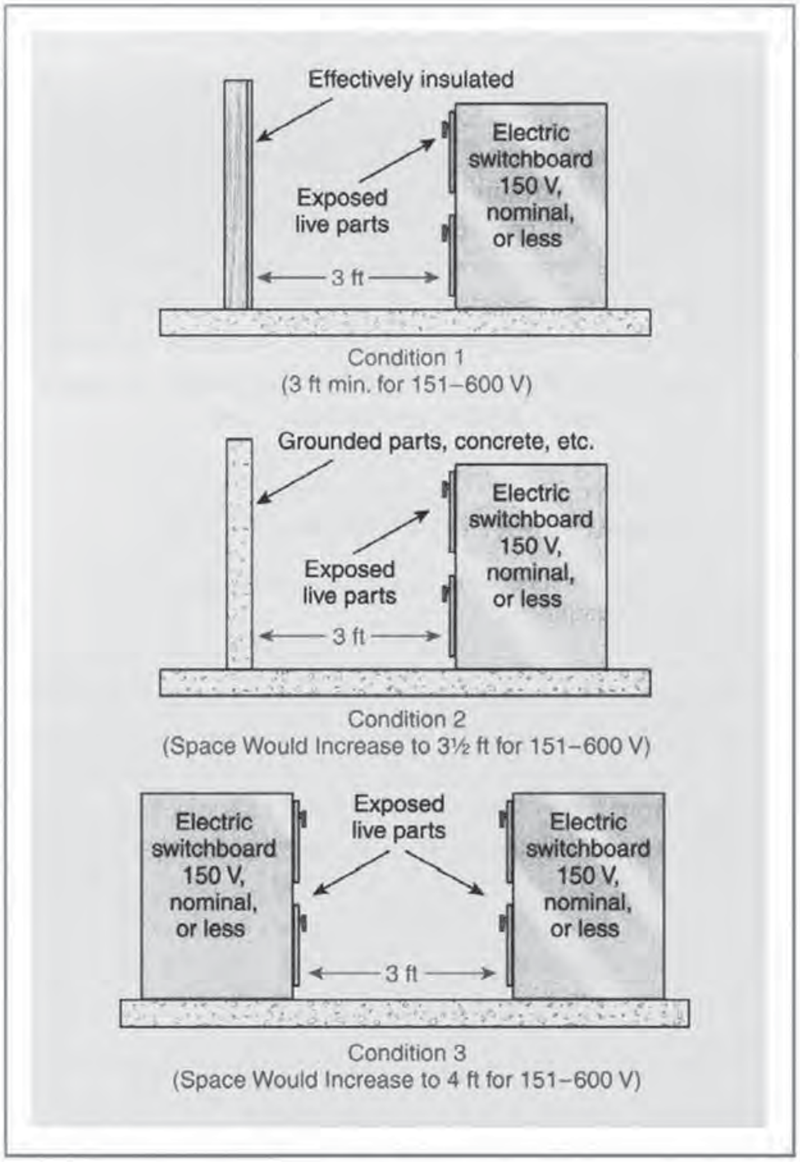
5. CLASS 1, DIVISION 1 and 2 LOCATIONS SHALL REQUIRE A MINIMUM OF 25 FEET CLEARANCE (e.g. PROPANE TANKS, GAS PUMPS, ETC. OR ANY PLACE WHERE VOLATILE LIQUID/GAS TRANSFER FILLING OCCURS) [SEE NEC ARTICLES 500–5(a)(3) and 450–27]

REFERENCE DRAWINGS

CS 3960 1Ø PADMOUNT TRANSFORMER 25–167kVA
CS 5315 3Ø 13kV–4kV 1500kVA STEP–DOWN TRANSFORMER
CS 5322 500 and 1000kVA NETWORK TRANSFORMERS
CS 5325 1500 and 2000kVA NETWORK TRANSFORMERS
CS 5362 3Ø 4kV OR 13kV 75–1500kVA "DEAD FRONT" TRANSFORMER

APPROVED BY DATE____	REVISION 8. 03/01: KEYSPAN FORMAT.	TRANSFORMER INSTALLATION AND HOUSING CONSTRUCTION: PAD AND ENCLOSURE HOUSED	CONSTRUCTION STANDARD DRAWN BY ETK		
LONG ISLAND POWER AUTHORITY prepared by KEYSPAN ENERGY		TRANSFORMER PAD LOCATION ADJACENT TO BUILDINGS	NUMBER 5370	SHEET NO 1 of 1	REV 8

FIGURE 26.8 Electrical equipment clearances. (Long Island Power Authority/LIPA)



Working Spaces

Nominal Voltage to Ground	Minimum Clear Distance		
	Condition 1	Condition 2	Condition 3
0–150	900 mm (3 ft)	900 mm (3 ft)	900 mm (3 ft)
151–600	900 mm (3 ft)	1.1 m (3½ ft)	1.2 m (4 ft)

Note: Where the conditions are as follows:

Condition 1 — Exposed live parts on one side of the working space and no live or grounded parts on the other side of the working space, or exposed live parts on both sides of the working space that are effectively guarded by insulating materials.

Condition 2 — Exposed live parts on one side of the working space and grounded parts on the other side of the working space. Concrete, brick, or tile walls shall be considered as grounded.

Condition 3 — Exposed live parts on both sides of the working space.

FIGURE 26.9 Low voltage working clearances. Reprinted with permission from NFPA 70®—2008, National Electrical Code®, Copyright © 2007, National Fire Protection Association, Quincy, MA. This reprinted material is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety.

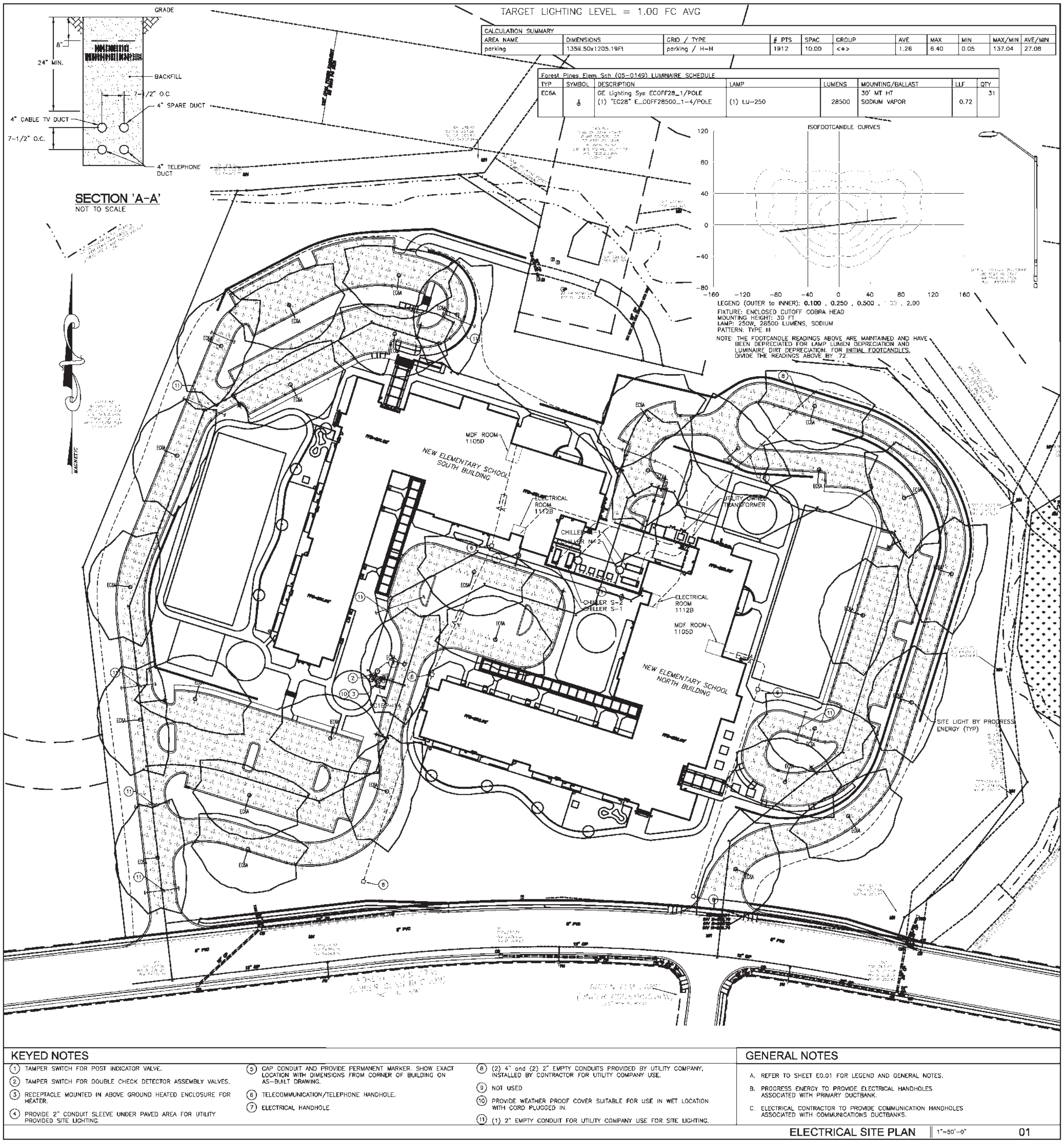


FIGURE 26.10 Electrical/telcom and site lighting plan. (Reprinted with permission of LS3P Associates)

Like all aspects of the land development design process, site lighting design is rather subjective, can vary greatly depending on the project requirements and goals, and rarely has a singular solution. That said, there are several procedural rules that should be implemented to ensure adequate quantity and good-quality lighting:

1. Engage a qualified lighting consultant. Site lighting plans may be prepared by the site's civil engineer, by the building or MEP engineer in cooperation with the civil engineer, or by an outside consultant who is a lighting specialist. Especially for projects with unique lighting requirements (high security, high-profile marketing, or unusual aesthetic components), a lighting specialist is recommended. This person should be determined during the concept design and included in the project design, development, and construction.

2. Determine applicable project lighting requirements. Review of local codes and ordinances should be performed to identify jurisdictional requirements. The owner/developer should be consulted regarding any project-specific requirements including such things as marketing or green building goals.

3. Assess the relevant design criteria. ASHRAE/IESNA Standard 90.1-2004 Exterior Lighting Section and IESNA RP-33 Lighting for Exterior Environments are the two guidelines commonly applied to site lighting design. These documents establish recommendations for lighting power densities (an energy efficiency measure) and illuminance, fixture lumen emittance angle, and light trespass (pollution measures) based on the zone or environment (four zones designated rural to urban) of the project. Local codes and ordinances may augment or more strictly enforce these requirements and should be consulted as indicated. Green building requirements (reference LEED-NC Sustainable Sites Credit 8 Light Pollution Reduction) have an interior lighting component that must be resolved with the building architect and MEP and also exterior requirements including a 20 to 50 percent reduction in the ASHRAE/IESNA guidelines depending on the lighting application.

4. Research equipment options. Luminaires can be full cutoff, semi-cutoff, or non-cutoff. (See Figure 26.11.) High-quality equipment chosen specifically for the application can improve the quality (by reducing glare), consistency, and sustainability of lighting in terms of both energy use and operations and maintenance costs. It may help to visit other sites with similar lighting applications as a component part of the research process.

5. Perform layout design. Once equipment is selected, a distribution diagram for the specific luminaire can be used to locate the fixtures. Most manufacturers will provide the distribution diagram. Siting fixtures requires a thorough understanding of the requirements, intuition, and an eye for detail, since this is both an engineering and an artistic exercise. Special care should be taken with siting fixtures adjacent to property lines, as these are the ones most likely to result in light trespass.

6. Develop a control program. Timers and sensors are important components of an effective lighting program. These features will facilitate meeting curfew hours (common in many jurisdictions) and can accommodate seasonal and climatic changes in lighting needs.

7. Model the lighting design. Many software packages exist to model lighting applications. Either a point-by-point illuminance analysis or iso-footcandle contour map can be used to assess the applicable illuminance levels and trespass. Lighting power density is typically examined in tabular form; the site data is compared to the recommended values.

8. Commission the lighting design. Commissioning is the verification and optimization process that follows construction; it is typically applied to building systems, including lighting, and is recommended for site lighting installations in order to optimize the user experience, energy performance, and operations and maintenance of the installation.

Site lighting is truly an art and a science and should be performed by experienced professionals with a varied background in exterior lighting applications. It is a critical project component that can drastically affect the end result and product reception. Lighting can make a statement when orchestrated artistically and with respect to the project and its surroundings. Site lighting should be accounted for in the scope, schedule, and budget of every project.

UNDERGROUND COMMUNICATION UTILITIES

Communications infrastructure comprises voice, data, and video services transmitted over copper and fiberoptic cabling. These services are often delivered from separate service providers (cable TV, local phone, and Internet service provider). This requires extra coordination effort because each service provider may have its own installation requirements, and often they do not like to share conduit systems or, in many cases, trenches if direct burial is permitted. This separation allows them to service, repair, or replace their cabling without disturbing another service provider's cabling. Table 26.3 lists common communication cable configurations and their uses. These cables are available in indoor, outdoor, and plenum-rated configurations appropriate for their application.

Many of the same design principles presented previously for underground electrical utilities are also applicable to underground communication utilities. Noteworthy variations that relate to ductbank design, proximity to other utilities, service coordination, and deliverables are presented next.

Ductbank Design

Often a service provider will require a larger conduit (say 5-inch diameter) containing several smaller inner ducts ranging from ¾ to 1½ inches, also known as *bundling*. This allows installation of additional cables in the future without damaging the cables already installed. Figure 26.12 shows a typical inner duct installation.

Burial Depth and Proximity to Other Utilities

Table 26.2 indicates burial depths dictated by the NEC for electrical installations. These guidelines are generally applied to communications infrastructure as well.

Access, heat, and electromagnetic interference (EMI) are the major concerns when considering separation from other utilities. EMI is generated within copper communications cables by the electromagnetic field emitted from nearby electric power cables. Field strength is inversely proportional to the square of the distance; therefore, interference diminishes rapidly as the separation is increased. The Telecommunica-

FIGURE 26.11 Luminaires. (© Bob Crelin, BobCrelin.com)

TABLE 26.3 Common Communications Infrastructure

COMMON COMMUNICATIONS CABLE TYPES	TYPICAL USES
Coaxial cable (copper)	Video
Category 5, 5e, 6, 6e (copper)	Data
Category 1, 3 (copper)	Voice
Multimode fiberoptic cable	Voice, data, video over short distances
Single mode Fiberoptic cable	Voice, data, video over long distances

tions Distribution Methods Manual (TDMM) recommends separating copper communications cables and electrical cables by a minimum of 24 inches. Crossing of electrical conduits should occur at right angles to reduce EMI. Fortunately, fiberoptic cables are immune to EMI, so they can be routed as close to electrical conduits as to other utilities such as water, sewer, and gas lines. Separation is generally a minimum of 12 inches.

Service Coordination

Close coordination between the designer and the many service providers of voice, data, and video is very important for a successful project. The service providers need a clear understanding of the project and its characteristics, and the designer needs a clear understanding of the service provider's standards and requirements. Information the service providers may request includes:

- A drop summary showing the number of voice, data, and video ports within the building (typically provided by the building architect or the electrical engineer and used by the service provider to select the appropriate service cable)
- A demarcation point, the location where the service provider's cable ends and the owner's cable begins (also known as the main distribution frame, or MDF)
- A site plan showing building footprint, public roads, parking areas, and proposed MDF
- A project schedule indicating construction start date and date services are required

Information the designer should gather from the service providers includes:

- Services available to the site (cable TV, dialup, DSL, fiber, and so on)
- Distance to nearest services
- Cost, if any, to extend service to site
- Schedule when service can be provided
- Service and MDF installation requirements
- Site plan approval showing MDF location, manhole locations, and routing of conductors to the building
- Division of work between contractor and service provider

Service and MDF installation requirements often include service conduit size and quantity (including spares), minimum bend radii, maximum number of bends, and burial depth and encasement requirements. Again, defining division of work is very important. Some service providers will provide and install all conduit and cable up to the MDF, while others will require the contractor to provide and install the conduit.

FIGURE 26.12 Inner duct photo.

Deliverables

Construction documents in the form of drawings and specifications must convey the scope of the work and also the division of work between the contractor and the utility company. Most construction documents include:

- Overall site plan
- Existing location of communication services
- Routing of conductors to building
- MDF location and layout
- Ductbank sections for each unique ductbank
- Manhole locations
- Manhole details and sections
- Ductbank profiles
- Location of any known crossings of existing utilities

In summary, dry utility design considerations filter through the entire site plan process from feasibility to final design. This aspect of the site-civil plan exemplifies the communication and coordination skills imperative to a good engineer and a successful project.

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CHAPTER 27

EROSION AND SEDIMENT CONTROL

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Updated/Revised: Brian K. Batten, PhD, Marshall N. Davidson, PE

INTRODUCTION

Erosion is the detachment and transport of organic and mineral particles caused by the forces of water, wind, and gravity. Sediment, the by-product of the erosion process, is the solid material that is in suspension or transport or has been relocated from its origin. Deposition of these particles is sedimentation.

Natural soil erosion and sedimentation are important processes responsible for the creation and evolution of natural landforms and essential for maintaining a balance between plant and animal life. Features such as the Grand Canyon, the badlands of the Dakotas, escarpments on mountains, fertile soils, and delta areas along rivers are the result of a slow, uniform process of erosion and sedimentation occurring over time. Deposition of nutrient-rich sediment contributes to the creation of topsoil and spurs vegetation growth, which, in turn, supports various animal species. Because of the long length of time required for this change to occur, ecosystems are able to gradually adapt to the changes.

Human-induced activities, such as logging, farming, and construction, cause erosion at greatly accelerated rates. Such activities alter the natural surface runoff patterns by denuding large areas of vegetation, loosening the soil, changing land slopes, and accelerating the time of concentration of site runoff, often through structural conveyance systems such as storm drains, open channels, and curb and gutter. Such extreme and rapid changes to the natural landform can increase the erosion rate from two to several tens of thousands of times the natural rate existing before the activity began.

The effects of erosion and sedimentation are recognizable immediately after a storm in the form of muddy runoff and sediment deposits on pavement or other low spots. Other impacts include degraded water quality with the associated harmful impacts on aquatic (benthic) organisms along with increased downstream flooding as sediment fills the channel or streambed and reduces the hydraulic capacity.

With careful planning and the use of appropriate control devices, excessive erosion and sedimentation can be greatly reduced during land-disturbing operations. This chapter discusses the causes and effects of erosion and sedimentation and focuses on the various mitigation strategies—planning and engineering methods—to minimize erosion and reduce sedimentation caused by land development and construction-related activities.

SOIL EROSION AND SEDIMENTATION PROCESS

The natural soil erosion and sedimentation process is an important factor in the formation of the surface features of the earth. These surface features, plant growth, and animal habitats are the natural result of a slow, uniform process occurring over geologic time; however, uncontrolled and/or accelerated erosion has damaging effects on the environment and compromises aesthetic values important to site development.

Design of a soil erosion and sedimentation plan for a development project requires a fundamental knowledge of the process itself. With a basic understanding of the principles of soil erosion and sedimentation mechanics, the engineer can then plan and design efficient methods for erosion and sediment control.

Soil erosion and sedimentation is a three-step process. First, the soil particles must be detached from the soil mass. Water (or wind) must then contain sufficient energy for entraining and transporting the particles. Finally, deposition occurs when the energy of the water (wind) is less than the fluid shear resistance and gravitational forces acting on the sediment particles. The key to erosion and sediment control is to prevent initial detachment of the soil particles and reduce the velocity of the runoff.

Detachment and Transport

Detachment of soil particles from the soil mass often begins when the energy of a raindrop impacting the ground is sufficient to break down the soil aggregates and project them into the air. Upon impact, these ejected particles then contribute to the detachment of even more soil particles. Soil particles can be ejected 2 feet into the air and may be displaced 5 feet in the horizontal direction. The detachment rate of the soil particles is a function of both the kinetic energy of the raindrop and the force holding the soil particle in place. Detachment occurs when the kinetic energy of the raindrop is greater than the total energy that holds the particle in place. The basic components of the particle energy are the intragranular frictional resistance, gravity, and chemical bonding. The most easily detached particles are the medium and coarse noncohesive particles. Cohesive clay particles have the highest resistance to detachment because of the strong intraparticle ionic bonds. The raindrop must carry enough kinetic energy to overcome this intraparticle bond for detachment to occur.

Raindrops vary in size, with the largest diameters approximately $\frac{3}{16}$ inch (5 mm). The velocity of the raindrop depends on its size. As the diameter increases, the terminal velocity increases up to a maximum of 30 mph (9 m/s) for larger raindrop sizes. Velocity and size are related to the storm intensity. The following summarizes the relationship between raindrop diameter, rainfall intensity, and velocity:

- As raindrop diameter increases, rainfall volume increases.
- The average raindrop diameter increases for low- to medium-intensity storms and decreases for higher-intensity storms.
- As raindrop diameter increases, the terminal velocity increases up to the limiting diameter of 6 mm.

The transport process begins with entrainment of the soil particle. That is, the soil particle is captured and pulled along by the combined effects of turbulence and momentum of the fluid. Heavier sediment particles near the bottom of the flow mass move by bouncing, sliding, or rolling. Flow turbulence lifts the lighter sediment particles and transports them in suspension. Whether the particle moves in suspension or along the bottom of the flow mass depends on the velocity and turbulence of the water and the physical characteristics of the particles themselves.

The common factor in detachment and transport is the energy of the agent. Rainfall acts not only as a detaching agent at impact, but also as the transporting agent as runoff in the erosion process. As runoff progresses through various flow regimes, the erosion process is often exacerbated.

Sheet Flow

After the soil has been fully saturated, the rain accumulates into small depressions of only several raindrop diameters deep. As the depression capacity is exceeded, the first phase of runoff, referred to as *sheet flow,* begins. On a macroscopic scale, sheet flow appears as a very shallow uniform depth flowing over the area. On the scale of a raindrop, it is a series of braided watercourses flowing in very small, unapparent channels. This type of flow usually lasts no more than several feet and only exists during the early part of the rainstorm. Typical velocity for sheet flow is around 1 foot per second (fps).

Rill Flow

Water transforms from sheet flow into rill flow as it moves downslope. As sheet flow depth increases beyond several raindrop diameters, the runoff begins flowing in more defined water courses several inches deep. This concentration of flow carries more momentum than sheet flow. Consequently, the erosive power and turbulence of rill flow are much higher than those of sheet flow. The relationship between velocity, erosive power, and transport capacity of flowing water is such that when the velocity doubles, the water breaks loose four times more soil particles and transports 32 times more sediment. Much soil erosion begins during rill flow.

Gullies

The next phase in the erosion process is the formation of gullies. Gullies are significantly larger than rills. These steep-sided watercourses with near vertical scarps at the head may be several feet to 15 feet (and larger) deep, twice as wide, and hundreds of feet long. Gully formation results from the merging of many smaller depressions. Overland flow and rain splash soak the soil to the point where the sides of these depressions erode away and slough to the bottom of the depression. As the sides of adjacent depressions wear away, the depressions combine as a larger one. The gully enlarges as the upslope water flows through the gully and further deepens it. Flows entering the head of the gully have very high erosive energies. Erosion in this part of the gully causes the movement of the gully to progress further upslope. Figure 27.1 shows the relative velocity during the various stages of the erosion process.

In land development projects, continuous grading and construction operations usually prevent gully erosion unless the site sits unprotected and remains unvegetated for very long. Typically, this is not the case if judicious land planning management is exercised during construction. Most eroded soil at construction sites occurs from sheet and rill erosion. Studies have shown that construction sites can produce 1 yd^3 of sediment per 100 ft^2 of cleared areas during a moderate storm event. Estimates of soil erosion rates for a high-

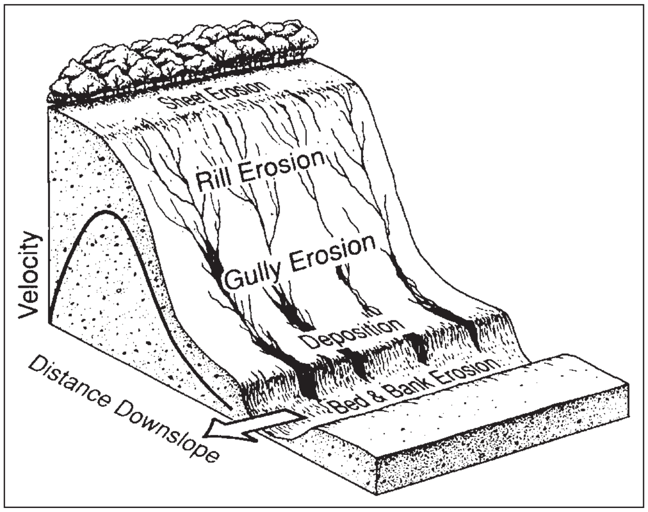


Figure 27.1 Relationship between runoff velocity and stages of the erosion process.

way construction project in Fairfax County, Virginia, range from 126 to 151 tons/acre/year. This compares to estimates of a natural erosion rate of 0.18 tons/acre/year for forests and 0.3 to 6 tons/acre/year for agriculture.

Soil erosion is a progressive yet discontinuous process. The soil particles are transported a fixed distance based on the energy of the flowing water. Eventually, the particles will again be entrained and transported farther downstream when higher erosive velocities recur. The following statements summarize the relationship of soil erosion and rainfall:

- Average soil loss per rain event increases with the intensity of the storm.
- Most erosion occurs from moderate storm events producing 1 to 2½ in of rain.
- The erosive power of water is related to the volume and velocity created by the storm.
- Any storm that effectively causes an increase in either of these two parameters poses a high erosion risk.

FACTORS INFLUENCING SOIL EROSION

The soil's erodibility (or propensity to erode) depends not only on soil characteristics but also on the region's type of vegetation, topography, and hydrologic conditions. The variability and nondeterministic nature of these factors adds to the difficulty in quantifying soil erosion to a high degree of certainty.

Soil Characteristics

Rainfall and flowing water erode the soil only if the energy is high enough to dislodge, entrain, and transport the soil particles. The minimum detachment, or threshold, energy that holds the soil particles in place and the energy required to start a particle in motion depend, in part, on the physical and chemical characteristics of the particle that are directly related to the soil structure and texture. Soil structure is the geometric arrangement of soil particles with respect to each other, that is, how the soil particles interlock. Soil texture is a measure of the particle size and gradation; it is the proportion of the sand, silt,[1] and clay content within the soil (see Appendix C for soil classification information). Noncohesive granular soil particles (e.g., sand) require the least energy for incipient motion. Clays and silts are platy and have strong chemical bonds. Thus, they require high threshold energy for incipient motion; however, their size (2 μm) makes them easily transportable once they are in motion. Generally, once the threshold energy is reached, the minimum energy to keep the particle in suspension or moving is considerably less. For those particles that move through rolling-bouncing-sliding motions, the rounder the particle, the less energy is required.

Two other factors that directly affect the erodibility of soil are infiltration and permeability rate. Soils that have high infiltration capacities and permeability rates are generally less erodible. These soils are able to absorb runoff and consequently reduce the available energy to surface soil particles. However, storms of sufficient duration will eventually exceed the soil's infiltration capacity. Once this happens, the soil becomes saturated and the benefits of the highly permeable soil are temporarily lost.

The following statements summarize the relationship between erodibility and soil texture:

- Soils containing high percentages of silts and sands are the most erodible. Their erodibility is magnified when these soils appear on steep slopes.
- Clean, well-drained, well-graded gravels are the least erodible. These soils have a high resistance to erosion because of their combination of cohesive and intergranular strength.
- Soils with higher clay content are less erodible, except the unstable clays, such as illite and montmorillonite, which have low infiltration capacities and are highly susceptible to erosion.
- Soils with high organics are more permeable, which allows for infiltration of higher amounts of rainwater and more resistance to detachment.

Vegetation

Vegetation is perhaps the most important factor in reducing soil erosion. Leaves, branches, and stems reduce the kinetic energy of the raindrop and thus reduce detachment. Some forms of vegetation are more effective at dampening the

[1]A distinction should be made between the terms *silt* and *sediment*. The two words are frequently used interchangeably, although this is incorrect. In the classification of soils, silt is the microscopic soil particles that consist of fine quartz grains and micaceous minerals. All transported particles, regardless of size or formal classification, are considered sediment.

kinetic energy than others. Ideally, the most effective vegetation would be strong enough to absorb the initial kinetic energy and close enough to the ground so that the subsequent kinetic energy of the collected secondary droplets is minimal.

At the ground surface, the organic litter and other plant debris reduce erosion in two distinct ways: they act as an additional energy-absorbing barrier, and, due to the layer and the shade from the foliage canopy, they reduce soil moisture evaporation. Moderate amounts of soil moisture enhance the stability of the soil aggregates.

Below the ground surface, the root system acts as a deterrent for erosion. Nearly 75 percent of the root system is located in the upper 12 inches of the soil. The root system, along with the surface debris, roughens the ground surface. These ground surface irregularities reduce flow velocity and dissipate flow energy, the consequences of which are a decrease in erosivity and the deposition of entrained particles. The increase in depression storage from the irregularities reduces runoff volume, which reduces erosion potential.

Soil Erosion on Slopes

Soil erosion rates are higher on slopes, with the highest erosion intensities occurring on convex slopes. Factors such as slope length, gradient, and geometric configuration all affect erosion potential. Because of the slope, rain splash dispenses more soil particles downslope than upslope. The amount dispensed downslope increases with slope gradient. For slopes of uniform gradient, the volume and velocity of the runoff increase as slope gradient and length increase. The tangential stress of the flowing water combined with the gravity component of the weight of the water in the direction of flow greatly increases erosion potential.

Soil Erosion from Snowmelt

Although the impact of falling snow does not contribute to the detachment of soil particles, the subsequent snowmelt and freeze-thaw cycles at certain times of the year can have dramatic erosive effects. As snow melts, it saturates the surface layer of the soil. If the immediate sublayers of the soil are nearly frozen, permeability and infiltration capacities are significantly reduced, resulting in a heavily saturated top layer or slurry. As the thaw continues, this soil slurry easily washes downslope with the snowmelt. At the next freeze-thaw cycle, the process repeats itself with the next available soil layer.

FACTORS INFLUENCING COASTAL EROSION

Nature's ability to shape the landscape is most apparent on the coastline. The forces of waves, tides, and currents are constantly and sometimes dramatically altering the shoreline. Variables that influence the erosion process include the frequency and intensity of storms, sediment supply, the characteristics of the near-shore sea bottom, and land management.

Coastal erosion, like soil erosion and the sedimentation process, is a natural process that shapes the features of the earth. As discussed previously, land development can accelerate the process of soil erosion, which leads to a degradation in water quality, an increase in flood hazards, and a reduction in hydraulic capacity and storage. Likewise, development compounds the coastal erosion process by creating static features in a dynamic environment. Development in close proximity to the shoreline is exposed to wave, wind, and flooding hazards, and therefore has a high potential for property damage. Despite the complex dynamics of the erosion process along the coastline and the development hazards it creates, the demand for view and waterfront property creates strong pressure for development.

The 30 coastal states of the United States contain approximately 85 percent of its population, and over 50 percent of the population resides within 50 miles of the coast. According to a study published by the Federal Emergency Management Agency in June 2000, approximately 25 percent of homes and other structures within 500 feet of the U.S. coastline and the shores of the Great Lakes will fall victim to erosion in the next 60 years. Property owners within the first few hundred feet of the nation's coasts face as large a risk of damage from erosion as they do from flooding. The study showed that development in several high-risk coastal areas has increased 60 percent over the last 20 years. This population explosion has resulted in development of property once considered to be swampland or too costly to develop, while the type of development has evolved from rustic beachfront cottages to multistory million-dollar residences.

In general, coastal erosion can be classified into two general categories: storm-induced and long-term. Storm-induced erosion from a hurricane, northeaster, or tsunami tends to involve larger-scale changes including shoreline retreat, dune erosion, and dune removal. In extreme events, such as category 4 and 5 hurricanes, barrier islands can be overwashed and flattened, completely inundated, or breached where barrier islands are narrow and low-lying. For mainland beaches, the dune field would experience severe erosion and removal, eventually exposing landward properties to wave impacts depending on dune volume and the height and duration of the storm surge. The magnitude of storm erosion is dependent on the intensity and duration of the event (see Figure 27.2). Storm-induced erosion response tends to have a high degree of spatial variability: it is dependent on the nearshore configuration of the seafloor, the width of the beach, and the size of the dune field prior to the storm.

Long-term erosion can be a result of several factors including, but not limited to, sea level rise, subsidence, and, most important, localized or regional deficits in sediment supply. Coastal erosion and shoreline retreat due to these factors can vary from 1 foot to tens of feet per year, depending on the factors involved. Many communities have instituted coastal setback statutes to balance development with the expected future position of the shoreline. Such statutes take the calcu-

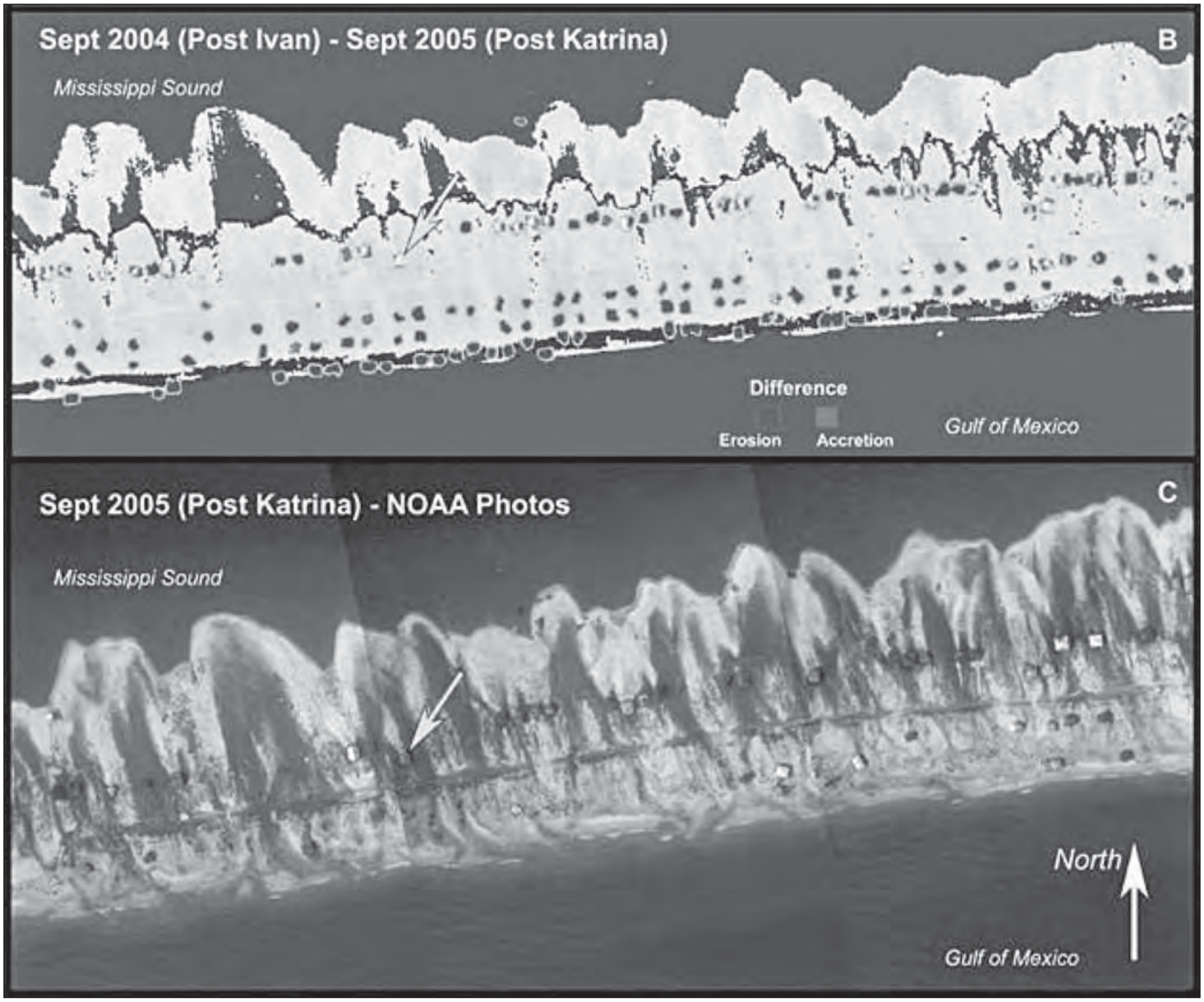


Figure 27.2 Impacts of Hurricane Katrina on Dauphin Island, AL. The island was completely inundated by the hurricane storm surge and suffered extreme erosion. Darker rectangles in the top frame indicate loss of a house. (Image courtesy of the USGS)

lated annual rate of long-term coastal retreat, delineate a regulatory line, and limit new development to areas landward of the line. This type of regulation is especially important in areas where long-term retreat rates are higher, since properties that appear to be protected by the fronting beach and dune field may be threatened in the near future.

Waves

Wave motion is the most important force in the natural process of accretion and erosion of a shoreline. Waves form as a result of wind moving over the ocean or water body surface. The characteristics of waves depend on wind velocity, duration, and amount of unobstructed water surface, referred to as *fetch*. Energy is transferred in the path of the wave until the wave encounters shallow water. When the water depth becomes approximately half of the wavelength (distance between wave crests), the wave will begin to shoal and dissipate energy. As the water depth decreases, the wave height will increase until the breaking depth is encountered, and at that point the wave energy will be released as the wave collapses. Beaches fronted by extensive shallow areas, such as reefs, are subject to less wave energy due to wave shoaling and breaking.

Wave height and wave steepness are the most important factors for determining the potential for erosion. Wave energy is proportional to wave height—the higher the wave, the greater potential for transporting material. The potential for moving material on- or offshore is dependent on the wave steepness. Steeper waves tend to transport material offshore, whereas less steep waves move material onshore. Thus, smaller waves can have a greater erosive impact than larger waves, depending on the wave steepness.

Beaches may experience seasonal cycles that are a direct reflection of changing wave conditions through the year, in particular, wave steepness. During late summer and early fall, beaches are typically in peak condition due to typically fair conditions through the summer months that produce small, longer-period, low-steepness waves known as *swell*. Through the winter months storminess increases, producing higher, shorter-period, steep waves, which erode and flatten the beach and transport material out to the offshore bar. During the late spring and summer months swell waves predominate, gradually moving this material back onshore and restoring the beach to peak conditions (see Figure 27.3). This cycle is also relevant to short-term beach evolution during and after storm events.

Tides

The gravitational effects of the sun and the moon in relation to the earth cause tides. The ebb and flow of tides produce regular changes in the level of the sea along the coast and generate tidal currents. The influence of tides on beaches depends on tide range, which determines the zone over which wave action can operate.

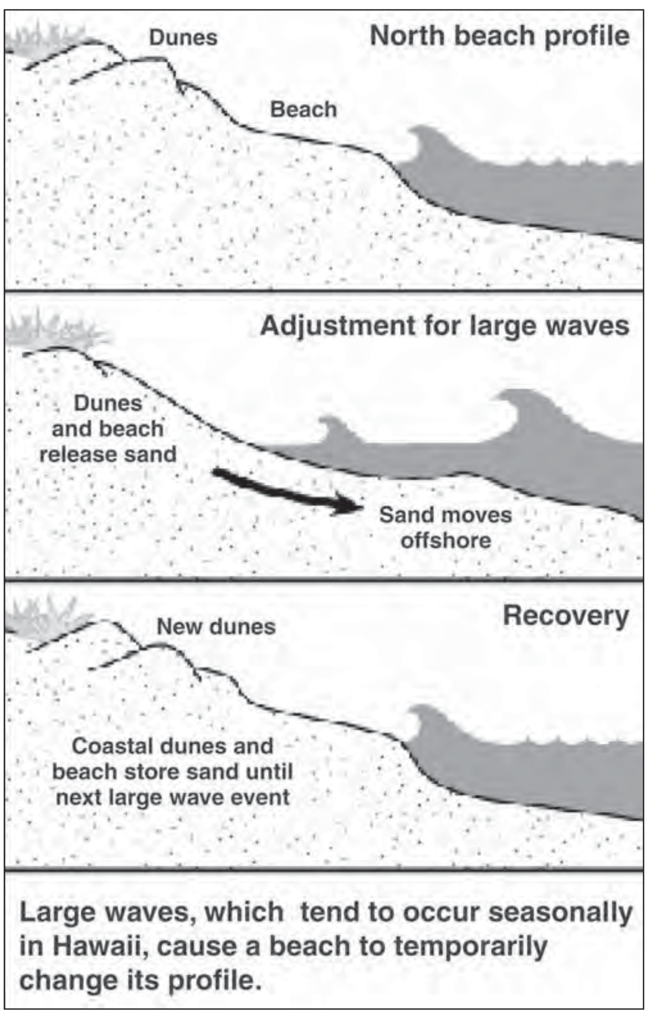


FIGURE 27.3 Seasonal beach profile adjustments. (*Source:* State of Hawaii, Department of Land and Natural Resources website)

Currents

Currents, the continuous movement of the water because of specific forces, have the capacity to carry large amounts of sedimentary material. Currents may or may not play a part in beach erosion, depending on the type of current, the flow velocity, duration, and location. Tidal and wave currents provide the greatest impacts with longshore sediment transport, the lateral transport of beach sediments along the coast, and tidal currents at inlets as the most significant to coastal erosion.

Waves approaching the shoreline at an angle induce what is known as *longshore current*. The height and angle of the approaching waves are the most important factors in determining the strength of the current. The higher the waves and the greater the angle to shore, the stronger the current and the greater the potential for sediment transport along the coast. The actual amount of transported material is dependent on the sediment supply and sediment grain size. The direction of longshore transport shifts with the predominant direction of wave energy. Seasonal changes in wave climate can result in reversals of longshore current along the coast. The total amount of material transported is known as the *gross longshore transport*, while *net longshore transport* refers to the amount of material transported in the dominant direction of transport. Changes in the nearshore bottom configuration can result in gradients in longshore transport. For example, a localized reach of shoreline with a deeper seafloor than adjacent areas would have a greater amount of wave energy closer to shore, resulting in a localized increase in the rate of longshore sediment transport. This area would experience a net loss of sediment, as the amount of material removed would be greater than the amount coming in. Gradients can also be a result of localized and regional changes in shoreline orientation.

Tidal currents at inlets (hydraulic connections between the ocean and another water body, such as a lagoon, bay, or sound) are the most frequent cause of erosion associated with currents. As tidal forces move water through an inlet, current velocities increase as the water is driven through the constricted opening. The increased water velocity scours sediment from the seabed and causes the channel to migrate if the entrance is not stabilized by jetties. Migration of the channel can eventually cause the current to come into close proximity with adjacent landforms and induce erosion.

Human-Induced Factors

Erosion can be accelerated by human alterations to the coastline. Hardening a coastline with structures can interfere with the natural movement of sediments in the complex coastal system (see Figure 27.4). Often, attempts to reduce erosion and stabilize one area of the coast result in increased erosion rates elsewhere. Beaches downdrift of groins and jetties are prone to erosion, as the structures interfere with the longshore transport of material. As a retreating beach encounters a seawall or revetment, it can no longer draw upon

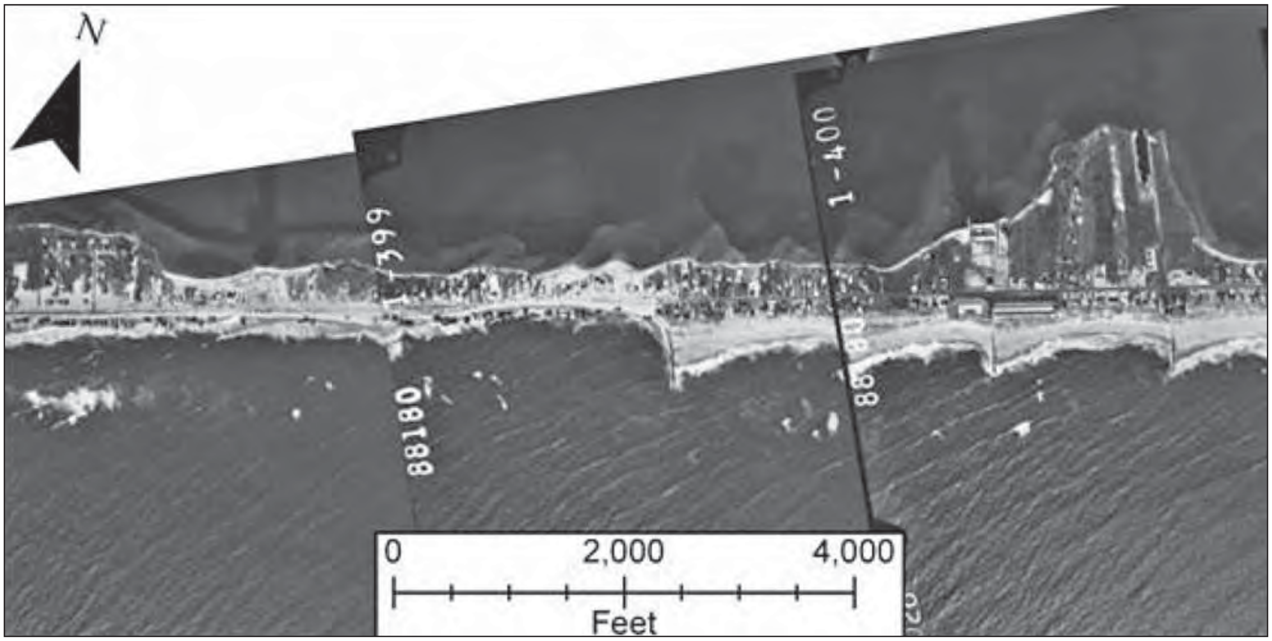


Figure 27.4 Shoreline hardening and beach loss—groin field in Westhampton, NY, 1988. (Aerial photograph courtesy of the U.S. Army Corps of Engineers)

the landward sand supply, and the fronting beach will become severely eroded. Human-induced impact on the natural vegetation of a dune system reduces the coast's natural ability to trap and retain material and decreases the stability of the dune.

EVALUATION OF COASTAL EROSION

Coastal erosion is typically evaluated through shoreline change, cross-sectional change, and sediment budget analysis. Shoreline change analysis involves compiling available historical aerial photographs for the study area, digitizing shorelines, establishing a baseline, and then determining change rates between the sample dates relative to the baseline. End-member and linear regression analyses are then conducted on the shoreline positions to determine change rates over the period of interest. Care must be taken that the photographs are generally at the same time of year to avoid seasonal fluctuations of the shoreline that may influence the accuracy of results. One must also ensure that the digitized feature, typically the mean high waterline, is consistent across the set of imagery. Photographs taken after storm events should be avoided, as they could also skew the analysis.

Cross-sectional profiles for coastal monitoring are typically collected on an annual basis. Profiles are analyzed for key parameters, typically volumetric changes of the beach and dune. Results are then compared to previous data to establish trends and to identify areas of higher vulnerability.

Sediment budgets provide a comprehensive assessment of sediment movement. These assessments begin with a conceptual model of all sediment inputs and deficits in the area of study. The study area is broken into a series of littoral cells, where quantifiable sediment fluxes are then assimilated in a reservoir model approach. Cells are delineated by nodes in longshore transport and by structures, inlets, or headlands. Fluxes in and out of each cell are tallied and balanced to determine a best estimate of sediment transport direction and magnitude. Sediment budgets serve as an informative tool to determine the impact of changes in inputs to the system as a whole (such as how constructing a dam on a river would impact erosion rates for coastal areas adjacent to the river mouth in the following 10 to 100 years).

ESTIMATING EROSION

Although it is not common to have to quantify erosion, there are several methodologies commonly employed that the engineer should be aware of, including their appropriate application and limitations.

The Universal Soil Loss Equation (USLE)

One of the most widely used and accepted equations for estimating soil erosion is the Universal Soil Loss Equation (USLE), an empirical equation developed by the U.S. Department of Agriculture. It was developed initially for agricultural purposes and since has been adapted to construction sites. The USLE applies to relatively large homogeneous soil areas and is based on long-term averages of rainfall and soil losses from runoff directly on the slope. It does not estimate deposition, nor does it estimate sediment yield at a downstream location. The USLE estimates the annual tonnage of soil eroded from the site attributed only to sheet and rill erosion. This easily converts into a volume, assuming a unit weight of soil.

Three common terms used in context with quantifying erosion are *soil erosion, soil loss,* and *sediment yield. Soil erosion* is the amount of soil moved by natural forces. *Soil loss* is the amount of soil moved off a particular area. *Sediment yield* is the soil loss delivered to a specific point. Sediment yield and soil loss are not necessarily equivalent. The amount of soil loss from a slope will be less than the sediment yield farther downslope because of deposition that occurs between the point in question and the base of the slope. Not all eroded soil qualifies as soil loss. Eroded soil may be redeposited before it leaves the slope and, therefore, does not factor into soil loss quantity. The USLE is

$$A = R \times K \times (LS) \times C \times P \tag{27.1}$$

where A is the average annual soil loss from sheet and rill erosion measured in tons/acre, R is the rainfall erosion index, K is the soil erodibility factor, LS is the length-slope factor, C is the cover factor, and P is the erosion control practice factor. Detailed information, including data tables, supporting equations, and mapping for determination of the various USLE terms, is found in the USDA's Agriculture Handbook No. 537, available online at http://topsoil.nserl.purdue.edu/usle/AH_537.pdf.

Morphological features of agricultural land are different from those of urbanized developing land. Agricultural land typically is characterized by relatively long, regular, gentle slopes, whereas construction sites may have discontinuous and irregular land patterns. The land patterns of a construction site are a combination of steep slopes, sharp breaks, excavation holes, and mounded piles of excavation soil. Since the USLE measures average annual soil loss, the erosion from the relatively short-term denuding–stabilization sequence, typical of a construction site, may not be indicative of the value obtained from the USLE. Runoff from an area above a disturbed slope was not a factor in establishing the USLE, yet runoff from upslope areas does occur on construction sites. Therefore, use of the USLE, especially for construction sites, requires the site area to be broken down into homogeneous areas. The USLE should be applied to each individual area with the sum of all areas as the more reliable soil erosion estimate.

The use of the USLE provides an estimate of the erosion potential of a site. Using the USLE to compare different practices at a construction site is appropriate; however, using the USLE to compare one construction site to another is not recommended. Furthermore, the equation is unable to account for the deposition that occurs in the nonhomogeneous irregular landforms typical of land development projects. Not all sediment eroded from a site can be classified as soil loss relative to the boundaries of the site, since some soil is redeposited on-site from natural deposition.

The Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is a widely used computer program developed by the USDA–Agricultural Research Service to estimate rates of soil erosion caused by rainfall and associated overland flow. The RUSLE, while still using the same terms, incorporates data and additional theory for describing hydrologic and erosion processes not included in the original USLE. The new data and additional theory have allowed for further refinement of the evaluating terms to suit conditions that are more specific. The current version of the model is available for download at http://www.ars.usda.gov/Research/docs.htm?docid=6010, or the original USDA Agriculture Handbook No. 703 can be accessed in full at http://www.ott.wrcc.osmre.gov/library/hbmanual/rusle/ah_703.pdf.

Water Erosion Prediction Project (WEPP)

The WEPP soil erosion model was developed by an interagency group consisting of the USDA–Natural Resources Conservation Service, USDA–Forest Service, USDI–Bureau of Land Management, and others involved in soil and water conservation and environmental land planning and assessment. WEPP was completed to replace the USLE and RUSLE. The USLE is applicable for predicting sheet and rill erosion. The WEPP model's overland flow profile simulations are applicable to sheet and rill erosion, while its watershed simulations are applicable to field situations with multiple profiles, gullies or grassed waterways, and impoundments. The current version of the model is available on the Internet at http://topsoil.nserl.purdue.edu/nserlweb/weppmain/.

CONSEQUENCES OF EXCESSIVE EROSION

Various types of nutrients and toxicants become attached to the surface of soil particles, and, when carried into streams, lakes, and other water bodies, their effect can be detrimental to aquatic ecosystems. Other effects of sedimentation include reduced hydraulic capacity of streams, resulting in higher flood elevations and loss of storage volume in lakes and ponds. At a more local scale, excessive and uncontrolled erosion can cause damage to adjacent properties such as lawns and landscaped areas, trees, sidewalks, and walkways, which can cause projects to be shut down as well as incurring costly fines and repairs.

Water Quality Degradation

High concentrations of natural soil nutrients, such as phosphorus, nitrogen, and their compounds, reside in the upper layers of soils. Clearing and grading operations expose much of these surface soils so that runoff carries the nutrient-laden sediment into streams, lakes, and ponds. As a result, the turbidity levels increase and the eutrophication process accelerates. The adverse effects of excessive sediments and adsorbed compounds can extend to the ecosystems at the water's surface, which rely on the water as part of their life support.

The injection of excessive sediments into the watercourse increases the turbidity, which reduces the amount of sunlight dispersed throughout the water. Decreased sunlight in the water creates fluctuations in the dissolved oxygen content and thermal stratification in the water. Aquatic life thrives within small variations of thermal conditions and requires specific amounts of dissolved oxygen, since existence depends on a stable environment.

Nutrients conveyed by sediment promote algae (algae bloom) and bacteria growth. A chain reaction begins with the proliferation of algae due to the abundance of phosphorus, commonly known as the *limiting nutrient.* As the algae propagate, they block sunlight to deeper areas of the water body. As the algae die off and fall to the bottom of the pond, bacteria decompose the algae and consume dissolved oxygen in the process, thereby depriving other organisms of much needed oxygen. Because of the reduction in dissolved oxygen levels, blocked sunlight, and changes in temperature and turbidity, aquatic organisms are either driven away or die off. While these impacts most immediately affect the benthic organisms and their deep zone or bottom habitats, their loss can greatly affect other creatures higher in the food chain. Many fish and shellfish feed on these benthic organisms, while underwater grasses serve as breeding grounds and shelter for young fish and shellfish. The disappearance of these habitats results in dead zones within the water body.

Reduction in Hydraulic Capacity and Storage

Many reaches of natural streams are in a state of equilibrium by balancing the water and sediment loads over a given period. When the balance is disrupted, the stream compensates by aggrading or degrading the bed and banks. Adding more sediment than the stream can convey causes deposition of sediments (aggradation). If the imbalance causes the stream section to carry less sediment than naturally supplied, the bed and banks begin to erode (degradation) to make up for the deficit. In each case the channel's hydraulic characteristics change, affecting the water level and associated floodplain along the entire watercourse. In the case of an aggrading stream, the water level tends to rise; thus, the likelihood of causing adjacent property damage as a result of flooding is increased. In the case of a degrading stream, huge loads of sediment can be released downstream. As the channel bank becomes destabilized, more bank failure is likely to occur until a stable angle of repose is achieved. The loss of streambank can affect adjacent property owners twofold by reducing the amount of land available for development, as property is literally washed away, and by potentially increasing the likelihood of flooding, as the channel has now migrated closer to the structure.

Sedimentation is not restricted to open channels; many land development projects incorporate lakes and ponds into the stormwater management design for control of postdevelopment runoff. Proper operation of these ponds depends on adequate storage volume to accommodate the excess runoff generated by development. Excessive sediment loads to these small ponds result in decreased capacity and significantly increased maintenance costs for dredging.

EROSION AND SEDIMENT CONTROL: PROJECT PRIORITY

Aside from protecting the natural environment and preserving the habitat of all creatures that use water resources (including humans who fish, swim, and enjoy aquatic activities), there are several other practical reasons for implementing proper erosion and sediment controls:

- If the topsoil washes off-site, the expense of hauling additional replacement topsoil for final stabilization can be high.
- If sediment from the site washes downstream onto someone else's property, significant cleanup expenses may be incurred and the construction site will likely be temporarily shut down by the regulatory agency (a huge loss in productivity). Worse yet, if wetlands or other environmentally sensitive areas are damaged, severe penalties from state and federal agencies for nonpermitted impacts are often issued and these areas are very difficult and labor intensive to clean.
- Many states and local jurisdictions require erosion and sediment control plans for the issuance of construction and grading permits. The National Pollution Discharge Elimination System (NPDES) Phase I and II permit requirements that evolved from the Clean Water Act of 1972 require an erosion and sediment control plan for any construction site over 1 acre (see Chapter 2). In some environmentally sensitive areas, local ordinances have reduced this threshold even further.
- If the project is pursuing a third-party green building certification such as USGBC's LEED certification, an erosion and sediment control plan, or Construction Activity Pollution Prevention Plan as it is referred to in USGBC's guidelines, is a prerequisite, that is, it is mandatory for any level of certification.
- Careful planning and implementation of the sediment control plans can result in cost savings. By stabilizing newly graded areas you can reduce or prevent erosion and the need to go back and regrade failed or eroded areas and slopes. With the tight budgets of today's construction jobs, this can be the difference in making a profit or losing money on a job.

EROSION CONTROL BEST MANAGEMENT PRACTICES

Erosion control best management practices[2] limit the amount of soil eroded from a site and indirectly control the sedimentation process as well. The objective is to prevent erosion on the site by controlling the energy, velocity, and volume of runoff.

Erosion control best management practices fall into three general categories:

- *Site management measures* limit erosion through judicious site planning and sequencing of construction operations.

[2]Some localities refer to best management practices (BMPs) when describing measures taken to remove soluble chemicals from stormwater runoff (SWM BMPs). In a broader sense, many other localities and the Environmental Protection Agency refer to all measures designed to improve water quality as BMPs, including those with the primary purpose of removing suspended sediment from stormwater runoff.

- *Soil stabilization measures,* either vegetative or non-vegetative, decrease the erosion potential of the soil.
- *Structural measures,* which take on various forms of devices, intercept and divert the runoff to stabilized collection areas or dissipate runoff energy.

Each of these measures can be classified as either a temporary or a permanent control. Temporary measures function for durations no longer than the construction period. Their purpose is to control erosion only until the immediate area is stabilized before they are removed. Although these temporary measures usually have low initial costs for installation, they have high maintenance costs due to the non-durable materials used. Permanent measures, which have higher initial costs for construction, are justified when considering the reduced maintenance costs and the longevity of the structure. The higher costs are attributed to the more durable materials and the detail involved in the design and construction of the device. The type of control selected is dependent upon the method of construction and the physical characteristics of the site.

Site Management Measures

Site management pertains to the general planning and scheduling of construction operations to reduce the site's erosion potential for the duration of the project. Careful site management can eliminate many potential erosion and sedimentation problems by preventing them from occurring in the first place.

Site Planning. The first and most effective measure for reducing the erosion potential of a site is limiting the amount of area disturbed. Erosion rates can be controlled by avoiding impacts to steep slopes (slopes greater than 15 percent) and highly erodible soils. Consider the use of retaining walls to reduce the development footprint and minimize impacts to these areas. Preserve natural drainage features and environmentally sensitive areas, thus also preserving natural vegetation and other areas that filter runoff and reduce erosion potential. Create and retain buffer zones to the environmentally sensitive areas to protect these areas from the adverse impacts of development; prohibit clearing and grading within these buffer zones. Clustering of units in a smaller land area is a planning tool that allows for the implementation of more effective perimeter erosion and sediment controls during construction, preserves natural drainage features and environmentally sensitive areas, and minimizes the amount of impervious area with reduced road lengths and parking areas. Reductions in the amount of impervious area protect the site's natural ability to filter and convey storm runoff. The use of porous paving materials and the reduction of building setbacks are planning measures that will reduce impervious area. The objective in this initial stage of site planning is to disturb the smallest area possible while developing the site in order to reduce erosion and off-site transport of sediment.

Limiting Denuded Area. The next step to take after reducing the area of disturbance is to consider whether the construction of the site can be staged to avoid areawide clearing (denuding of the site). It is difficult to recommend a rule of thumb to use for the maximum amount of area allowed to be denuded. Most localities have a set limit, by ordinance, on the amount of area that may be denuded at any one time. Other localities limit the extent of time a disturbed area can remain unworked without stabilization by mulch or temporary vegetation. This limit is often set at 14 days with reduced time limits (7 days) in critical areas such as steep slopes. In those instances where there are no local criteria, or where the criteria do not apply, the engineer must rely on experience and judgment. The engineer must be sensitive to both the environmental consequences and the cost effectiveness of construction processes when developing a recommended sequence of construction to accompany erosion and sediment (E&S) plans.

On one extreme, it is impractical for builders to denude a 100-acre parcel if they can effectively work in only 5- to 10-acre sections at a time. The other extreme is when the amount of disturbed land is so limited that builders are restricted in their ability to perform the task without substantial increases in the construction cost. The amount of land that is workable on a steady basis by the builder varies from project to project and from builder to builder. Limiting the amount of denuded area at one time is practical for projects that have sufficient area to allow for such phasing.

Sequence of Construction. After the initial site planning measures are incorporated, the engineer should begin preparation of a sequence of construction. The sequence of construction is the formal guidance to the contractor on how to construct the project. The sequence is prepared by the engineer in the form of a sequential outline of the construction process detailing how the construction activities are to proceed while providing flexibility for the contractor. All sequences specifically detail when E&S controls are to be installed or removed (i.e., install perimeter controls prior to beginning rough grading operations, or stabilize upstream drainage areas prior to removal of inlet protection devices) and when stabilization/construction operations should occur (usually grading operations begin after erosion control devices are in place and once the phase/section is completed, the area must be stabilized before proceeding to the next phase). The sequence is typically found along with other notes on the E&S control plan sheets. Additional notes on the plans, or in the erosion control device details, specify a maintenance schedule for the inspection and upkeep of E&S control devices.

For complex construction situations, the engineer may decide to meet with the contractor before specifying construction staging or land phasing in the sequence of construction. During this meeting, the engineer can learn the contractor's approach for staging and phasing of the particular project. The two parties can then work toward establishing a sequence of construction that meets the developer's needs and provides flexibility to the contractor while protecting the environment and meeting regulatory requirements at the same time.

Revisions to the Sequence of Construction. Construction operations are subject to weather conditions and availability of materials and subcontractors. Also, site conditions (high ground water, bad topography) or an oversight in the plans may require the contractor to adjust the sequence or modify the sediment control plans. However, this can be done only with the regulatory agency approval. The process for obtaining approval of revisions varies depending on the agency and type of change proposed. The contractor is strongly encouraged to discuss the revision procedure with the regulatory agency prior to beginning any construction activities in order to establish the proper protocol and avoid costly delays. Typically, minor changes can usually be solved in the field through collaboration with the jurisdiction's field inspector, while major design alterations may require formal engineering plan review. One should not avoid seeking revisions if better protection of the environment can be achieved and if significant cost savings can be realized. Most regulatory agencies want to work with the builder/contractor to meet their goals and will, in appropriate situations where environmental considerations warrant, expedite the process.

Soil Stabilization Measures

Soil stabilization measures are nonstructural controls that prevent erosion by absorbing rainfall energy, reducing overland flow velocity, increasing infiltration, helping to retain soil moisture, and even binding the soil particles together to stabilize the soil. Soil stabilization measures include various vegetative ground covers such as grass seeding, straw, wood chips, and shredded bark or synthetic alternatives (often biodegradable) such as binders or soil stabilization nets or matting.

Grass and Mulch. The preferable form of vegetative ground cover, where sufficient rainfall is available, is grass. It is the easiest and fastest to install and, relative to other forms of vegetative covers, it has low maintenance costs. Grass seed mixtures are regionally developed to suit climate, soil conditions, and maintenance expectations. Some species of grass are not recommended for steep slopes or other special conditions. Local design manuals, soil conservation district offices, and, often, the extension service of a local university provide planting information. Of primary importance when installing the grass seed is the need to keep the seed from washing or blowing away. This can be ensured by proper soil preparation with appropriate fertilizers and roughening the soil surface to promote germination. Mulches are then added, as a temporary cover, to protect the grass seed while it is germinating. Additionally, mulches provide temporary surface soil stabilization until the grass can grow and stabilize the area. The most commonly used mulches are hay and straw. For maximum effectiveness, these mulches must be tacked, usually with hydromulch, to prevent the wind from blowing them away.

Grasses can be permanent or temporary. Temporary grass should be used if the site will be redisturbed within a relatively short period of time, commonly one month to a year, as these grasses usually are grown for just one growing season. For long-term (more than a year to remain undisturbed) or final stabilization, permanent grasses should be used. The type of grass species selected should take into account future maintenance requirements—is this on a steep slope that might not be mowed frequently so that the grass species selected should grow to only a certain height or will this area be regularly maintained? Mowers and tractors are difficult to operate on slopes steeper than 3H:1V. Although steep slopes optimize land use, they also make maintenance difficult. In general, the steeper the slopes, the less frequently maintenance operations should be expected. Although the easiest form of planting grass is seeding, sprigging and sodding are other methods used to establish grass cover. Table 27.1 lists selected mulches and the recommended rates of application.

TABLE 27.1 Organic Mulch Materials and Application Rates

Mulches	Rates: Per Acre	Rates: Per 1000 ft^2	Notes
Straw or hay	1½–2 tons (Minimum 2 tons for winter cover)	70–90 lb	Free from weeds and coarse matter. Must be anchored. Spread with mulch blower or by hand.
Fiber mulch	Minimum 1500 lb	35 lb	Do not use as mulch for winter cover or during hot, dry periods.* Apply as slurry.
Corn stalks	4–6 tons	185–275 lb	Cut or shredded in 4–6 in lengths. Air-dried. Do not use in fine turf areas. Apply with mulch blower or by hand.
Wood chips	4–6 tons	185–275 lb	Free of coarse matter. Air-dried. Treat with 12 lb nitrogen per ton. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand.
Bark chips or shredded bark	50–70 yd^3	1–2 yd^3	Free of coarse matter. Air-dried. Do not use in fine turf areas. Apply with mulch blower, chip handler, or by hand.

* When fiber mulch is the only available mulch during periods when straw should be used, apply at a minimum rate of 2000 lb/ac or 45 lb/1000 ft^2.

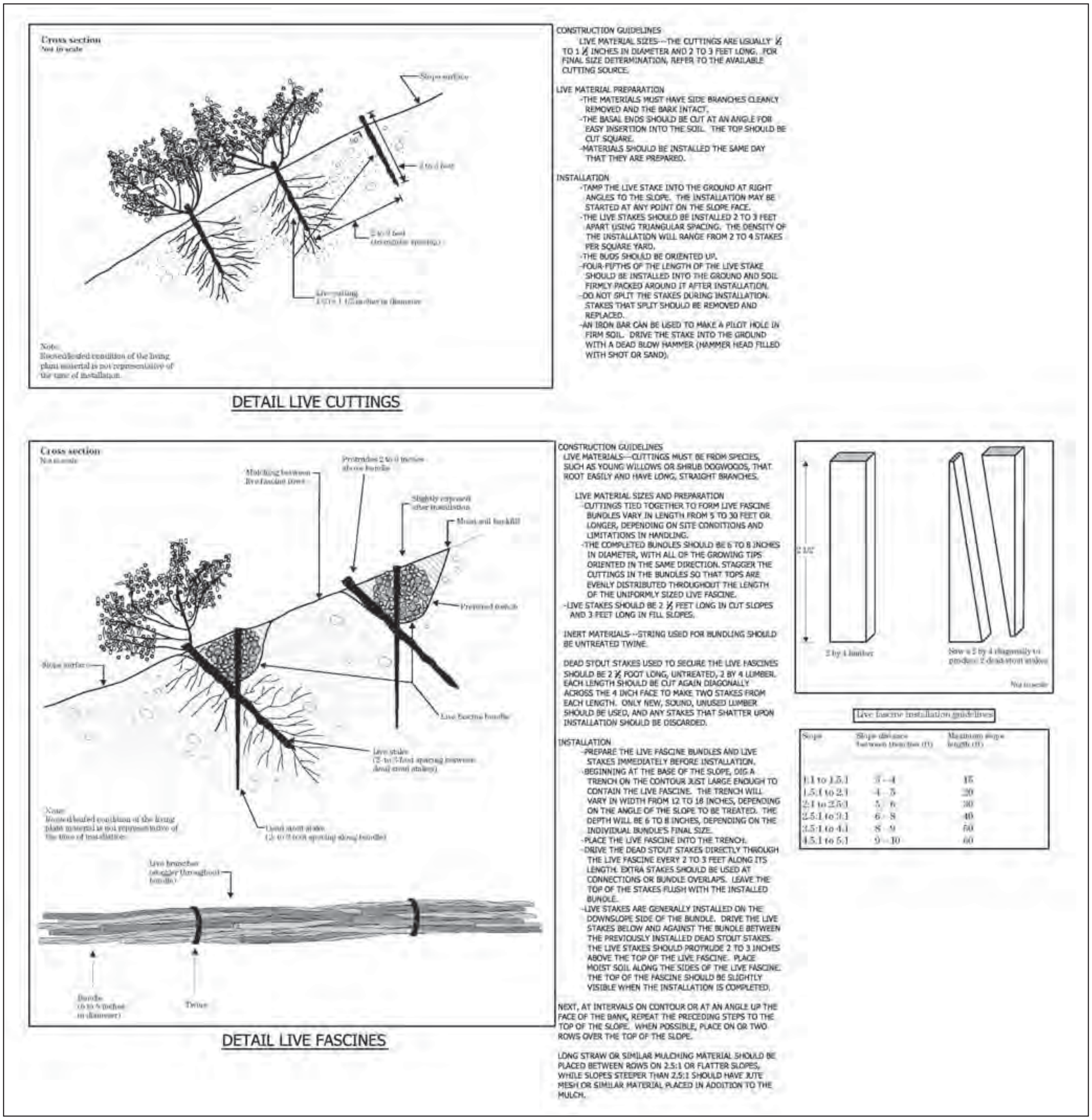


FIGURE 27.5 Soil bioengineering techniques. (U.S. Department of Agriculture, 1992)

Soil Binders. Soil binders are chemicals and synthetic materials sprayed onto the soil surface in order to bind the soil particles together or to protect seeding and sprigs from washing away. These are emulsions or dispersions of vinyl compounds, rubber, or other substances that are mixed with water and applied to the soil. Soil binders are most effective when sprayed over an organic mulch to keep it from blowing away. Alone, soil binders do not have the capability to insulate or retain moisture and are easily damaged by traffic. The soil binders decay within 60 to 90 days of application.

Soil Stabilization Nets and Mattings. Nets and mats are also a form of ground cover. Nets are a heavy, uniformly woven cloth, most notably jute yarn. Soil stabilization mattings are porous materials that are sometimes referred to as *erosion control blankets*. The mattings are used when erosion is likely to occur and wash away the soil before vegetation can be established. Soil stabilization mattings are made of either natural degradable materials, such as coir fiber or straw in a natural netting that is used for a short duration until vegetation is established and the matting degrades, or

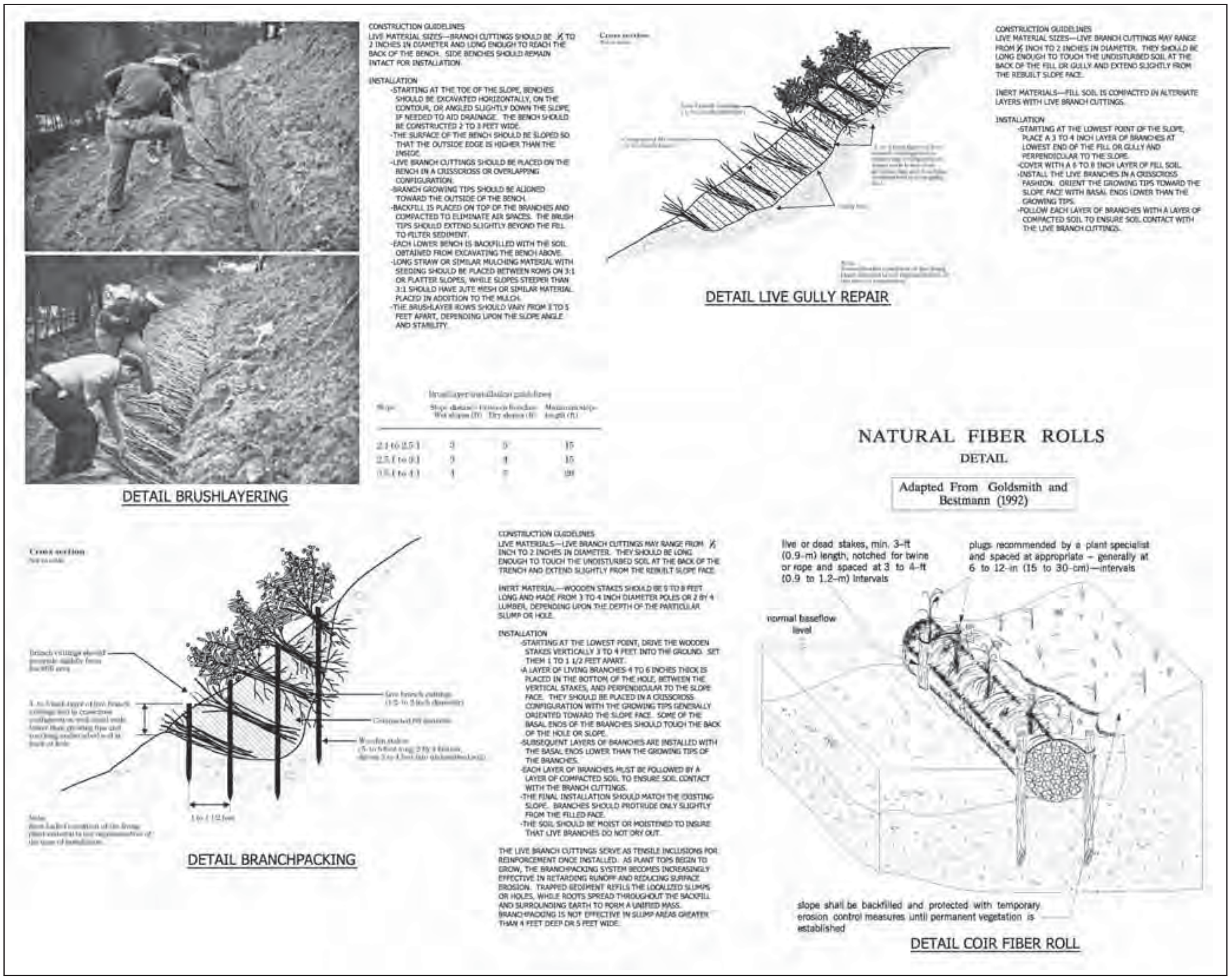


Figure 27.5 (*Continued*)

permanent synthetic materials for use in high-velocity areas to provide permanent stabilization even after vegetation has been established. The mattings are rolled over the newly graded and seeded area to prevent the seed and soil from washing away during rain events. To be effective, nets and mats should be in contact with the soil surface and anchored securely.

Soil Bioengineering. Historically, methods of controlling slope erosion, stream flow, and wave-induced erosion have included structural practices like riprap, sheet piles, and retaining walls. These traditional approaches are often not effective in environmentally sensitive areas when the objective is to limit disturbance and preserve the aesthetic quality of the natural setting. Soil bioengineering techniques use combinations of live vegetation, sometimes in conjunction with structural practices, to achieve erosion protection. The advantages of soil bioengineering solutions include environmental benefits of protected/enhanced wildlife habitat; improved water quality and aesthetics; improved strength and stability over time as vegetation becomes established; reduced construction access requirements; and limited maintenance costs. Soil bioengineering is a diverse, multidisciplinary, and rapidly growing field that requires the knowledge of engineers, botanists, horticulturists, hydrologists, soil scientists, and construction contractors. Soil bioengineering uses vegetation to reduce erosion, off-site sedimentation, runoff velocities, and promotion of runoff infiltration.

Examples of soil bioengineering techniques (Figure 27.5) include contour wattling, brush layering, branch packing, and coir fiber rolls. Guidance on the application and construction of these techniques can be found in the *USDA Soil Conservation Service Engineering Field Handbook,* Chapter 18.

Contour wattling is used to break long slopes into shorter slopes by planting bundles of live branch cuttings (called *wattles* or *fascines*) in shallow trenches at regular contour intervals along the slope. After staking the wattles in place with either live or dead stakes, only the top of the wattle is exposed. When installed properly and cut from native plants, they will root and immediately begin to stabilize the slope. The selection of native planting material provides the

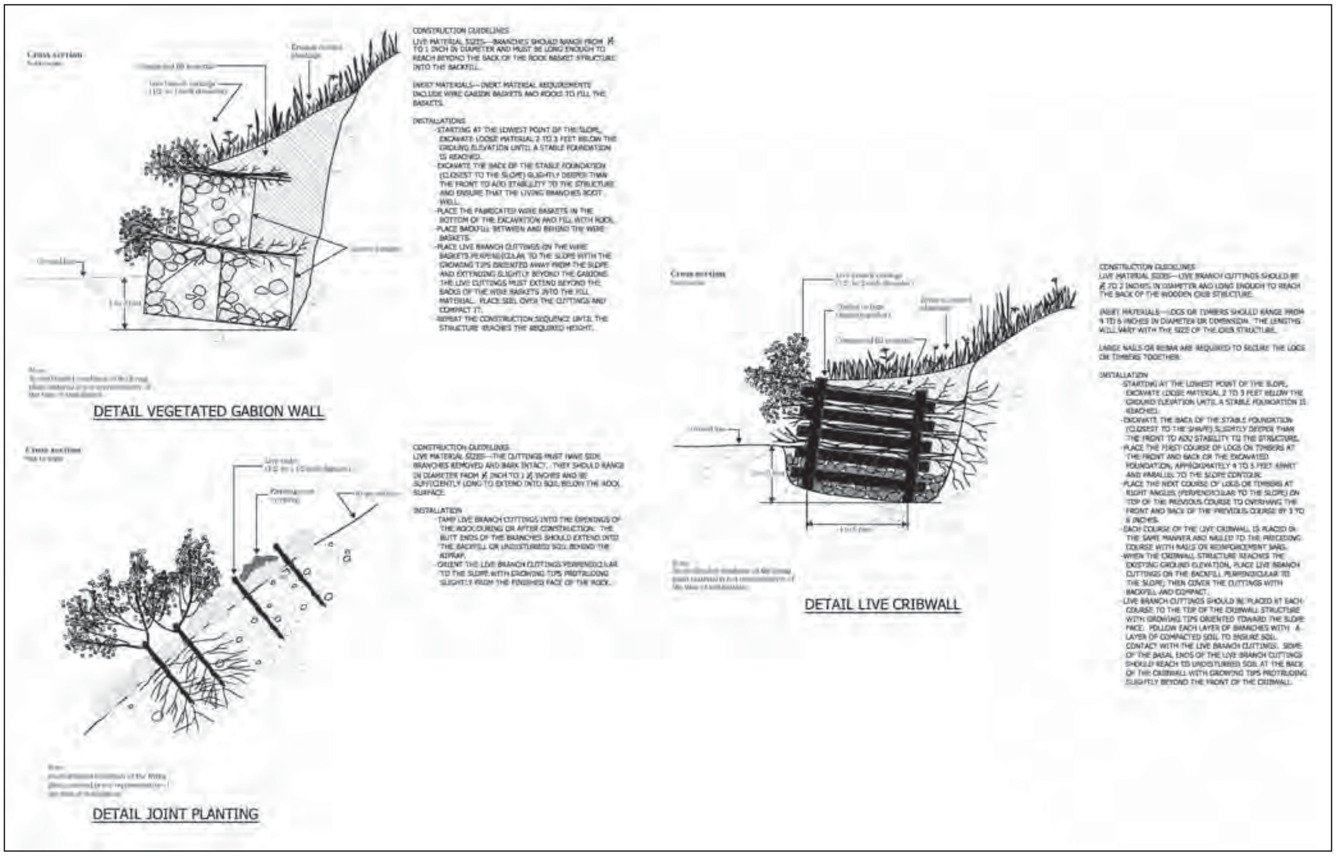


FIGURE 27.5 (*Continued*)

best chance of survival for the vegetation and subsequent stabilization of the slope.

Brush layering is another method of restoring slopes by constructing a fill slope of alternating layers of live branches and soil, creating a series of reinforced benches. Brush layering is similar to contour wattling, except the branches are oriented perpendicular to the slope. The brush layers are placed along small 2- to 3-foot-wide benches cut into the slope. The practice is recommended for slopes up to 2H:1V and not greater than 15 feet in vertical height.

Branch packing is a concentrated use of brush layering to repair small, localized areas of slope failure or slumps. Branch packing is most effective in slumps or holes less than 4 feet deep and 5 feet wide. The cuttings or live stakes are installed similarly to those in a brush layering system and supplemented with wooden stakes to stabilize the area.

Coir fiber rolls are tightly bound cylinders of coconut fiber (coir fiber) held together by a coir fiber netting. They are generally available in 10- to 20-foot lengths and are 10 to 12 inches in diameter. The rolls are installed at the toe of slopes and are used to restore streambanks and wetlands where a natural look is desired. They are excellent at providing toe protection where scour is not severe. Once installed, the coir fiber log becomes saturated with water and vegetation can be planted directly in it. Coir fiber rolls provide a natural, unobtrusive appearance while immediately stabilizing the toe of the slope. Over a three- to six-year period, the coir decomposes and leaves the roots of the established vegetation to secure the toe of the streambank. They are relatively lightweight (10-ft length = 75 lb) and can be installed with minimum site disturbance. The only limitations to coir fiber rolls are that in areas of severe bank scour they are not appropriate, and also there must be sufficient sunlight available to promote plant growth.

Coir fiber rolls are installed by excavating a shallow (3- to 4-in-deep) trench along the toe of the stream bank. The coir fiber log is placed in the trench so that the bottom and back are in contact with the stream substrate and the stream bank. Stakes are then driven down along its sides. Coir or nylon twine is woven between and around the stakes and the stakes are driven in firmly, securing the coir fiber log to the streambed. The stream bank above the coir fiber log is stabilized using other bank stabilization techniques—see Appendix B for additional details.

Riprap or gabions are often used to protect stream banks and lakeshores. In some instances, live cuttings can be planted within the riprap or gabions to provide additional slope stability. Root growth through joints or gaps in the stone improves the soil strength and presents a more natural look as the vegetation leafs out and hides the rocks.

In areas where space is limited and the stabilization has to extend vertically (in the past, a retaining wall may have

TABLE 27.2 Approaches to Upland Slope Protection and Erosion Control

	Category	Examples	Appropriate uses	Role of vegetation
LIVING			**VEGETATIVE PLANTINGS**	
	Conventional plantings	Grass seedlings Transplants Forbs	Control water and wind erosion. Minimize frost effects.	Control weeds. Bind and restrain soil. Filter soil from runoff. Intercept raindrops. Maintain infiltration. Moderate ground temperature.
			SOIL BIOENGINEERING	
	Woody plants used as reinforcement, as barriers to soil movements, and in the frontal openings or interstices of retaining structures.	Live staking Live fascine Brushlayer Branchpacking Live cribwall Live gully repair Vegetated rock gabion Vegetated rock wall Joint planting	Control of rills and gullies Control of shallow (translational) mass movement Filtering of sediment Improved resistance to low to moderate earth forces	Same as above, but also reinforce soil, transpire excess water, and minimize downslope movement of earth masses. Reinforce fill into monolithic mass. Improve appearance and performance of structure.
NONLIVING			**VEGETATED STRUCTURES**	
	Inert structures with vegetative treatments.	Wall or revetment with slope face planting. Tiered structures with bench planting.	Control erosion on cut and fill slopes subject to scour and undermining.	Stop or prevent erosion and shallow sloughing on or at the slope face above the toe.
	RIGID CONSTRUCTION	(See Chapter 6, "Structures," of the *Engineering Field Handbook*).		

been used), the best solution may be a *live cribwall.* Live cribwalls use a combination of live woody cuttings with timbers, logs, or other similar structural materials. These materials are interlocked to form a hollow, boxlike structure that is filled with backfill material and layers of live branch cuttings.

Soil bioengineering measures are not appropriate for all slope failures and slope erosion problems—see Table 27.2 for additional guidance. In some cases with more gradual slopes, grass seeding and hydromulching may be satisfactory and less costly. In other cases, due to steeper slopes, higher scour velocities, significant lateral earth stresses, and other factors, it may be more effective to use structural retaining systems alone. There are several limitations to bioengineering: the installation season is often limited to the plant dormant season when site access may be limited, the availability of locally adopted plants may be limited; the availability of adequate sunlight due to existing tree canopy may be limited, experienced labor may not be available, and installers may not be familiar with bioengineering principles and designs and require training. However, with the right situation and opportunity, soil bioengineering practices can successfully stabilize slopes and reduce erosion while saving money and providing a more natural vegetated appearance. An understanding of these techniques—their function and appropriate application—is increasingly important given the increased emphasis throughout the land development industry on low-impact development (LID) techniques.

Structural Control Measures

There are practical and economical limits to the effectiveness of site planning on controlling erosion from a site. Structural erosion controls are used to supplement soil stabilization and site management controls. Structural controls redirect runoff, dissipate runoff velocity, or intercept runoff and temporarily store the "dirty water" long enough to allow sedimentation.

Diversion Berms/Earth Dikes. Compacted earthen berms (Figure 27.6) stabilized with vegetation or mulch are used to

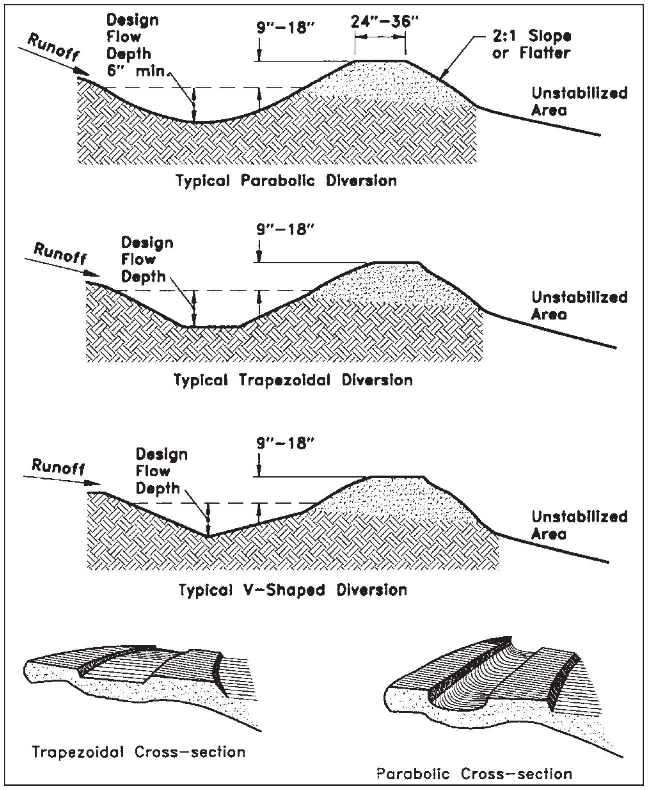


FIGURE 27.6 Typical diversion berms. (Adapted from ULI, ASCE, and NAHB. 1978. *Residential Erosion and Sediment Control.* Reproduced by permission of ASCE)

direct or divert runoff. These berms are placed on natural grade around the perimeter of the disturbed area on the high side (upslope). The berms (sometimes referred to as *perimeter dikes* or *clean water diversion dikes*) divert clean runoff around the disturbed area to limit the amount of runoff flowing into the work area (see Figure 27.7). The low side of the dike directs runoff, which has fallen directly on the disturbed area and is heavily laden with sediment, to a sediment-trapping device for filtering.

Diversion berms/earth dikes are compacted to increase their resistance to erosion and for stability purposes. The compaction is typically done by driving the earthmoving equipment along the sides and ridge of the berm. Depending on the soil used for the berm and the height of the berm, the compaction operation may have to be performed in approximately 1-foot lifts. Berms should be stabilized with vegetation or stone to ensure their durability. Berms should not be installed across swales or ditches that convey appreciable amounts of concentrated flows. The longitudinal grade (i.e., parallel to the berm) on the side of the flow should be sufficient to ensure positive drainage to the outlet. Minimum grades of 1 to 2 percent suffice in most cases. Construction of grades less than 1 percent in bare soil is difficult to achieve and may not drain properly. Steep longitudinal slopes will result in excessive velocities and may erode the toe of the berm. Longitudinal slopes should keep velocities less than 3 fps. If velocities approach 5 fps, special precautionary construction measures such as the use of erosion control mattings, riprap/stone armoring, or the addition of an adjacent conveyance channel should be considered.

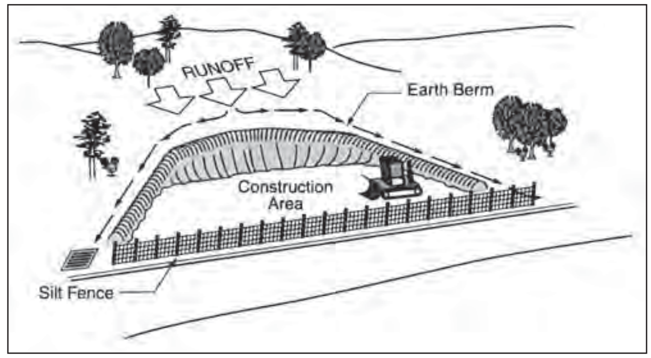


FIGURE 27.7 Diverting runoff around the construction site. (From Goldman, S., et al. 1986. *Erosion and Sediment Control Handbook.* Reproduced with permission of McGraw-Hill)

Channel Conveyance. Shallow ditches are used to convey small quantities of concentrated flow safely and without erosion. As the flows increase, a more refined ditch design is necessary. Ditches are typically prismatic in cross section (e.g., trapezoidal, parabolic, and rectangular) and the type of lining in the channel coincides with the expected design velocity. Channels excavated in earth are most effective with a trapezoidal cross section and the side slopes less than the

TABLE 27.3 Permissible Velocities for Earth-Lined Channels

SOIL TYPES	PERMISSIBLE VELOCITIES (FPS)
Fine sand (noncolloidal)	2.5
Sandy loam (noncolloidal)	2.5
Silt loam (noncolloidal)	3.0
Ordinary firm loam	3.5
Fine gravel	5.0
Stiff clay (very colloidal)	5.0
Graded, loam to cobbles (noncolloidal)	5.0
Graded, silt to cobbles (colloidal)	5.5
Alluvial silts (noncolloidal)	5.0
Alluvial silts (colloidal)	5.0
Coarse gravel (noncolloidal)	6.0
Cobbles and shingles	5.5
Shales and hard pans	6.0

(*Source: Virginia Erosion and Sediment Control Handbook.* 1992.)

TABLE 27.4 Permissible Velocities for Grass-Lined Channels

Channel Slope	Lining	Permissible Velocity (fps)
0%–5%	Bermuda grass	6
	Reed canarygrass, tall fescue, Kentucky bluegrass	5
	Grass-legume mix	4
	Red fescue, redtop, sericea lespedeza, annual lespedeza, small grains (temporary)	2.5
5%–10%	Bermuda grass	5
	Reed canarygrass, tall fescue	
	Kentucky bluegrass	4
	Grass-legume mix	3
>10%	Bermuda grass	4
	Reed kanarygrass, tall fescue, Kentucky bluegrass	3
	(For highly erodible solids, decrease the above velocities by 25%)	

(*Source: Virginia Erosion and Sediment Control Handbook.* 1992.)

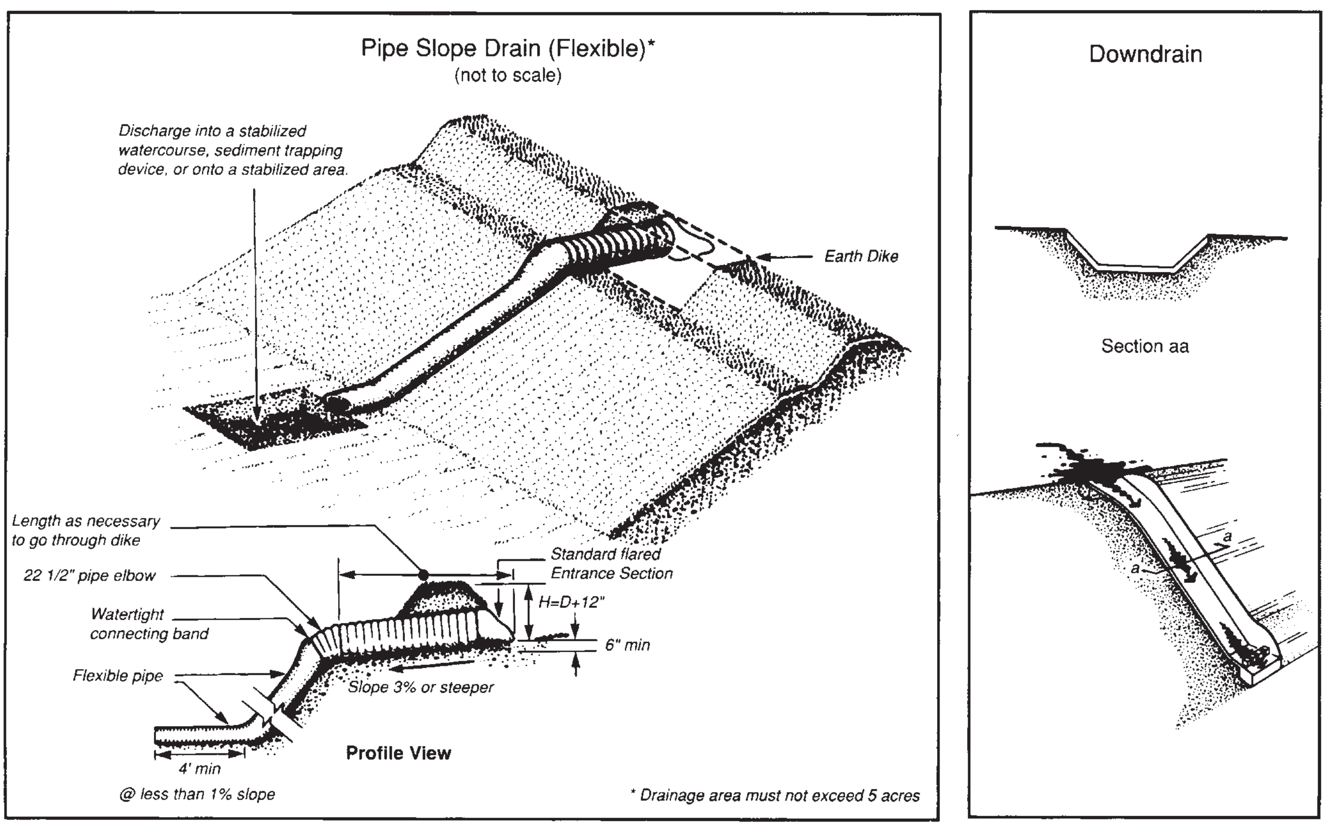


FIGURE 27.8 Slope drain. (*Source:* USDA, Soil Conservation Service)

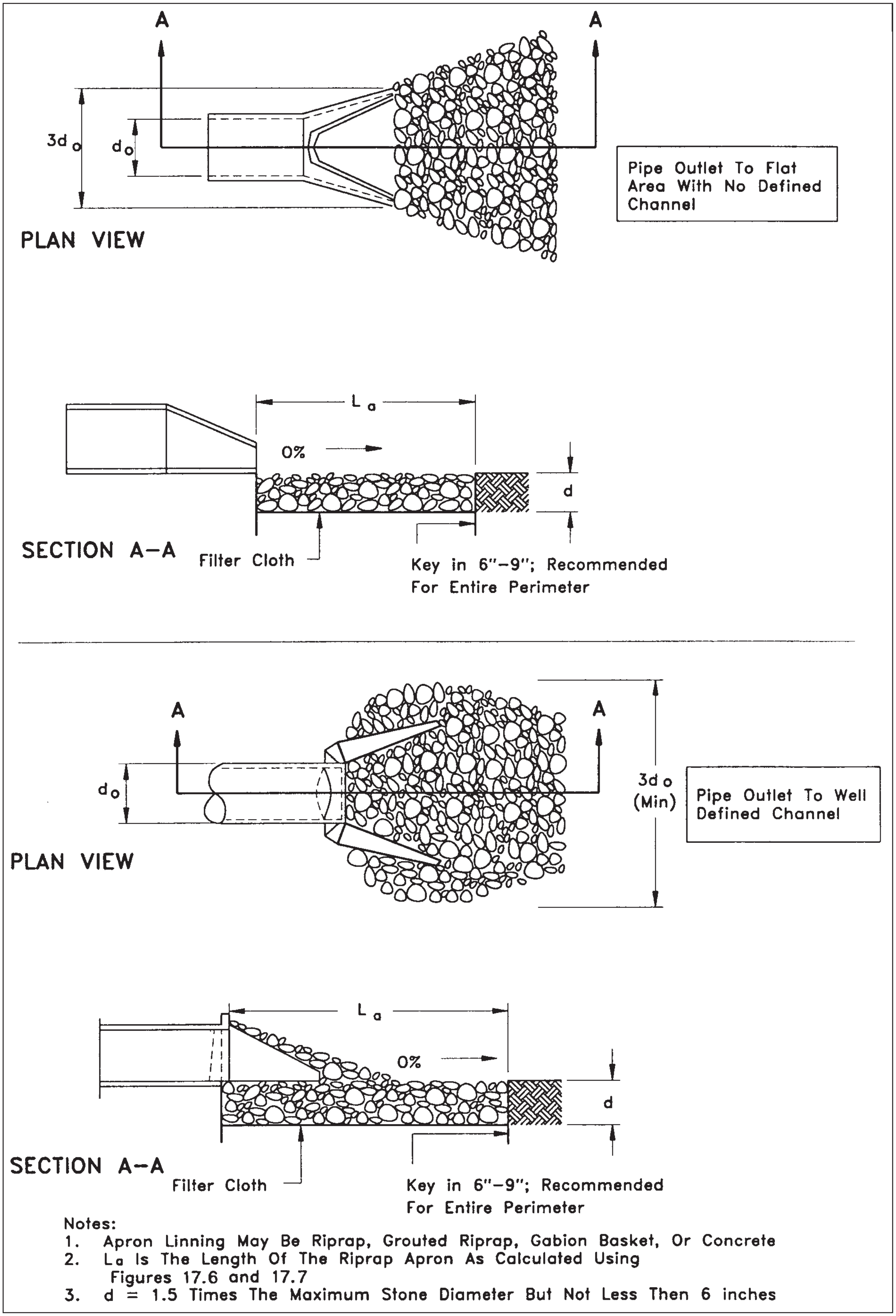


FIGURE 27.9 Pipe outlet conditions. (*Source: Virginia Erosion and Sediment Control Handbook*, 1992)

angle of repose of the saturated bank soil. Angles of repose vary from less than 15 degrees for soft clays to over 40 degrees for large, angular, noncohesive gravels. For normal design practice, maximum side slopes of 2H:1V function adequately over the range of these angles of repose.

Tables 27.3 and 27.4 identify various linings and the recommended velocities for grass- and earth-lined channels. Use Manning's equation to check the velocities in the channel and compare the velocity to the velocities given in Table 27.3 or Table 27.4. When selecting the lining, consider whether the channel will be temporary or permanent. If additional velocity dissipation is required beyond what is achieved through installation of a liner, check dams (discussed in detail later) should be provided.

Slope Drains. If runoff needs to be conveyed along the surface of a highly erodible area or steep slope, then another method for conveying runoff should be used. As shown in Figure 27.8, temporary slope drains or stabilized flumes (downdrains) can be used to convey flow over the face of a slope without damage.

Temporary slope drains consist of either flexible pipe (usually HDPE) or rigid pipe (PVC or even CMP). The drains are installed on the face of the slope and anchored securely. At the entrance of the slope drain, a berm diverts the upslope runoff into the slope drain and keeps the flow from sheeting over the exposed face of the unstable slope. The force of the water flowing through the slope drain, along with the vertical component of gravity acting on the drain itself, puts tension at the pipe's joints. Consequently, joints that are not connected and anchored securely will separate and result in costly repairs and extensive erosive damage.

Downdrains or flumes are less common in practice than slope drains. The flume may be any common channel shape—typically, V-ditch or trapezoidal—and is stabilized with geotextile fabric, riprap or gabions, or concrete in the case of long-term installations and lengthy or excessively steep slopes. Outlet protection is critical, as excessive velocities may be achieved; an energy dissipation device (or plunge pool—see next discussion) may even be warranted.

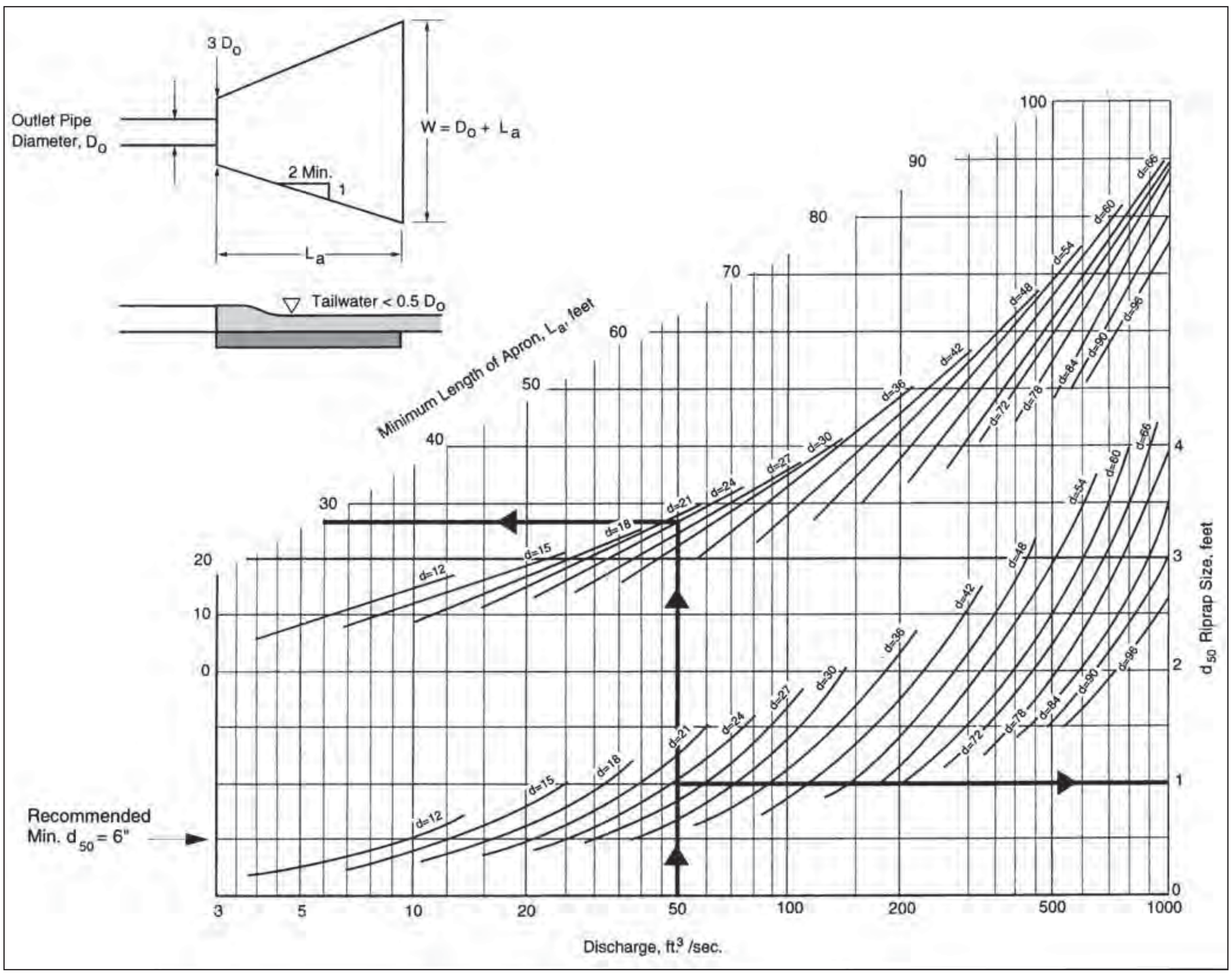


FIGURE 27.10 Design of outlet protection for round pipe flowing full ($T < 0.5 * d$). (*Source: Virginia Erosion and Sediment Control Handbook,* 1992)

Outlet Protection. Outlet protection is used at the discharge end of a slope drain, flume, storm drain or culvert discharge, and open channel. It consists of a structurally lined apron or other type of device that reduces the erosion potential downstream by dissipating the flow energy and allowing flow to transition back to the natural channel. In addition, outlet protection prevents scouring at the base of the slope and underneath the discharge end of the outlet pipe.

Depending on the flow energy, the apron may consist of riprap, grouted riprap, gabion baskets, recycled concrete, or other types of structurally sound material adequate for the hydraulic conditions. Figure 27.9 shows two methods for pipe outlet protection depending on whether the structure discharges into a well-defined channel or a flat, level area. Figures 27.10 and 27.11 provide the recommended apron length and stone size for a given pipe diameter flowing full. Figure 27.10 is used to size riprap outlet protection stone when the prevailing tailwater depth at the discharge end is less than one-half the diameter of the pipe. Figure 27.11 is used when the tailwater depth is greater than or equal to one-half the pipe diameter.

EXAMPLE 1

Given a pipe diameter of 24 inches, full flow conditions with $Q = 50$ cfs and TW $< 0.5 * D_o$, find the length and width of the outlet protection apron.

From Figure 27.10 for $Q = 50$ cfs and $d = 24$, read $d_{50} = 1$ foot.

On the upper pipe diameter scale, read $L_a = 28$ ft for $D_o = 24$.

Then $W = 2 + 28 = 30$ ft.

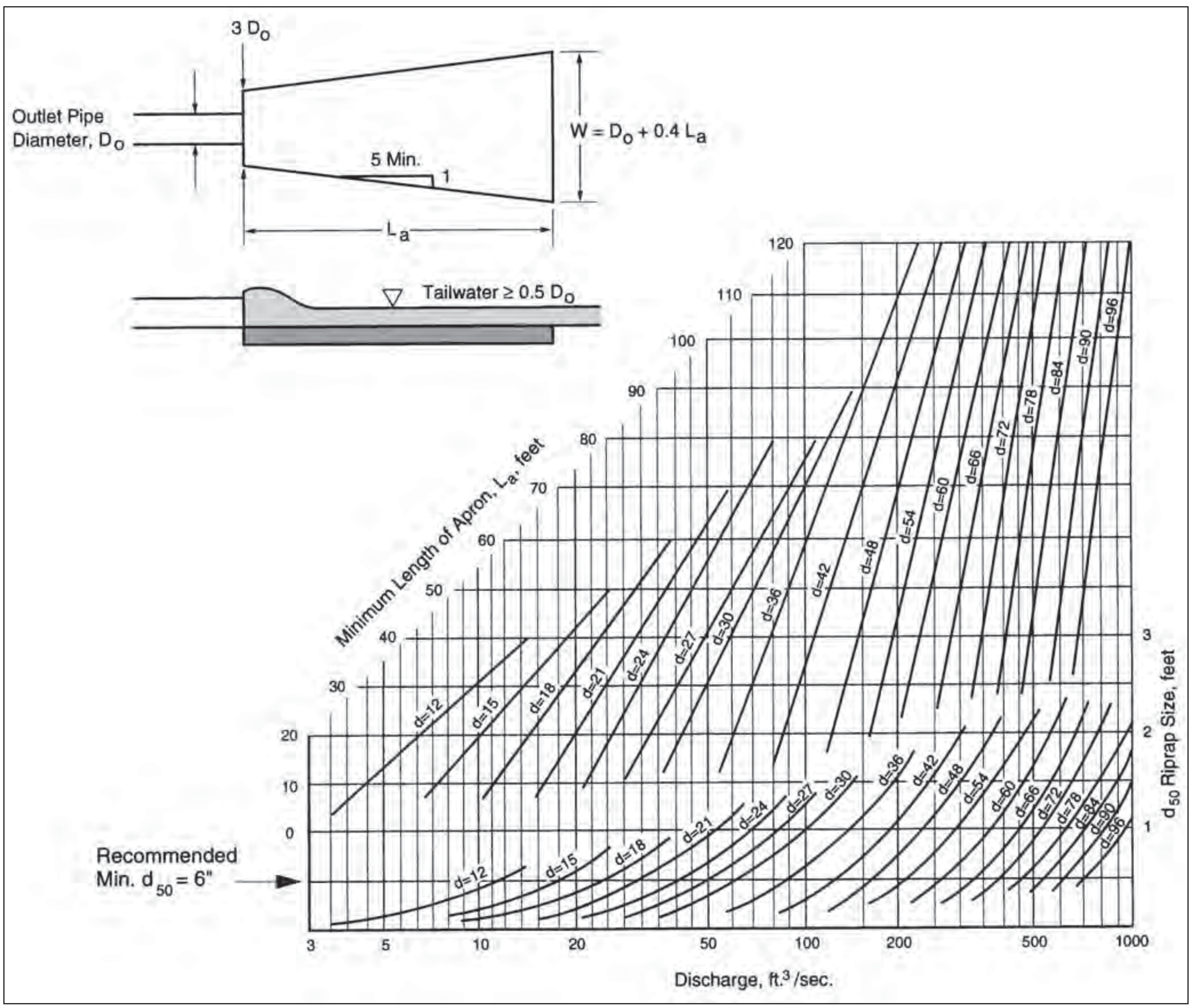


FIGURE 27.11 Design of outlet protection for round pipe flowing full ($T \geq 0.5 * d$). (*Source: Virginia Erosion and Sediment Control Handbook*, 1992)

The length of protection can be judged based on the magnitude of the exit velocity compared with the natural channel velocity. The greater the difference, the longer the length of riprap outlet protection necessary. When outlet protection lengths are not feasible due to property constraints—outfall is too close to another property owner who has not granted discharge permission, or the outfall is adjacent to wetlands or other environmentally sensitive areas—other methods of dissipating the energy should be considered. One method to consider is the use of plunge pools. Plunge pools are riprap-lined pools that dissipate the outfall velocity/energy over a very short length by using a pool of water in a rock-lined channel. The specific design requirements are covered in *The Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14,* published by the U.S. Department of Transportation, Federal Highway Administration (accessible in full at http://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf). Many state and local regulatory agencies have established their own design criteria for plunge pools as well.

Check Dams. Check dams are stone structures installed across relatively steep conveyance channels at periodic intervals to temporarily detain the water (or *check* the velocity), thereby reducing erosion while vegetation is germinating. Check dams are not installed in live streams. Although some sediment removal is expected through filtering, the use of check dams solely as filtering devices is not recommended. This practice is to reduce flow velocities.

Check dams can be constructed of stone aggregate ¾ to 2½ inches in diameter for smaller drainage areas, and of stone riprap or even gabions up to 6 to 12 inches in diameter on the downstream side of the check dam for larger drainage areas. The material is placed across the channel from top of bank to top of bank, with the center of the dam 6 inches lower than the top of bank. The upstream and downstream faces of the stone check dams have slope gradients of 2H:1V. Spacing of the check dams is such that the toe of the preceding upstream dam is at the same elevation as the top of the subsequent downstream dam. Figure 27.12 shows a typical layout of check dams.

During high flows, water can pond behind the check dam and flow over the 6-inch-deep weir in the center of the check dam. Erosion of the check dam and the banks at each end sometimes occurs after heavy rainstorms; the contractor must inspect the check dam and channel for any erosive damage after each storm event to confirm proper operation and make any necessary repairs.

Level Spreader. The level spreader is a device that converts concentrated flow back into sheet flow. The level spreader is an excavated depression with a level grade across the face of a stabilized slope. Concentrated flow enters the level spreader and fills the depression. When the capacity of the depression is exceeded, the flow uniformly spills over the lip and down the stabilized slope as sheet flow (see Figure 27.13).

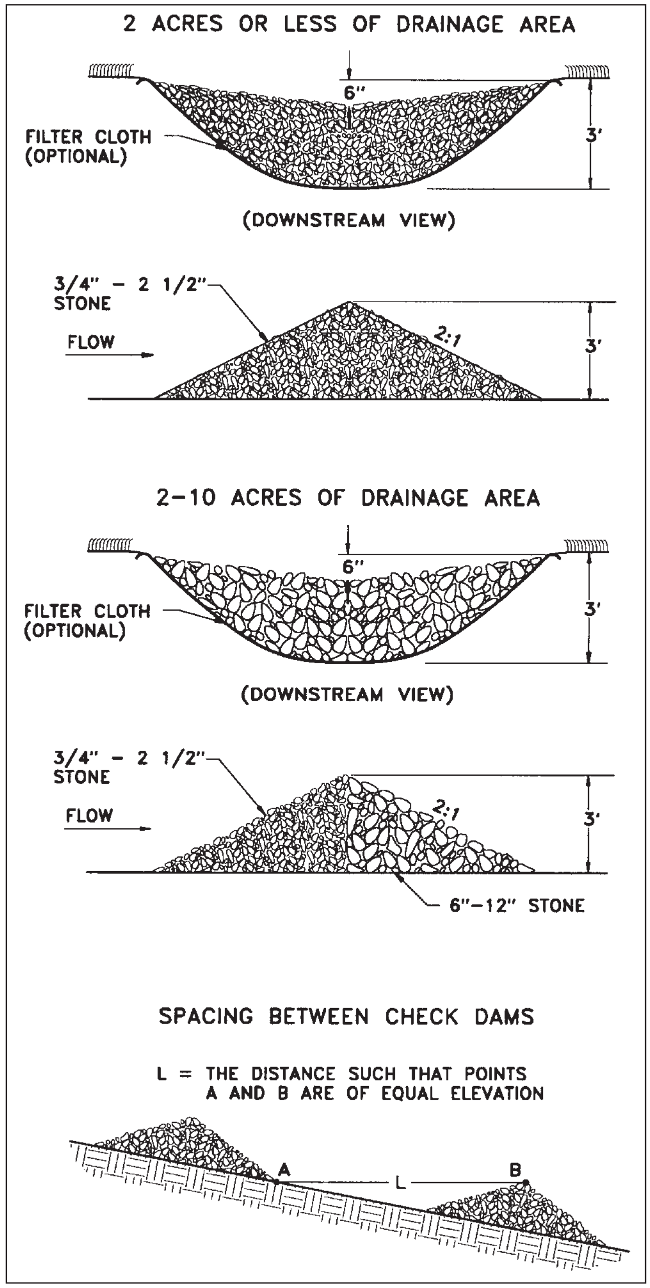


Figure 27.12 Construction details for check dams. (*Source: Virginia Erosion and Sediment Control Handbook,* 1992)

The effectiveness of the level spreader depends on strict adherence to construction specifications. The minimum depth of the level spreader is 6 inches and is uniform across its length. Limiting the maximum velocity of the water entering the level spreader to 3 fps prevents scouring within the spreader. The grade across the spreader is flat and should remain flat during its term of operation. The slope of the ground below the level spreader should be 10H:1V or flatter to keep the exiting sheet flow from

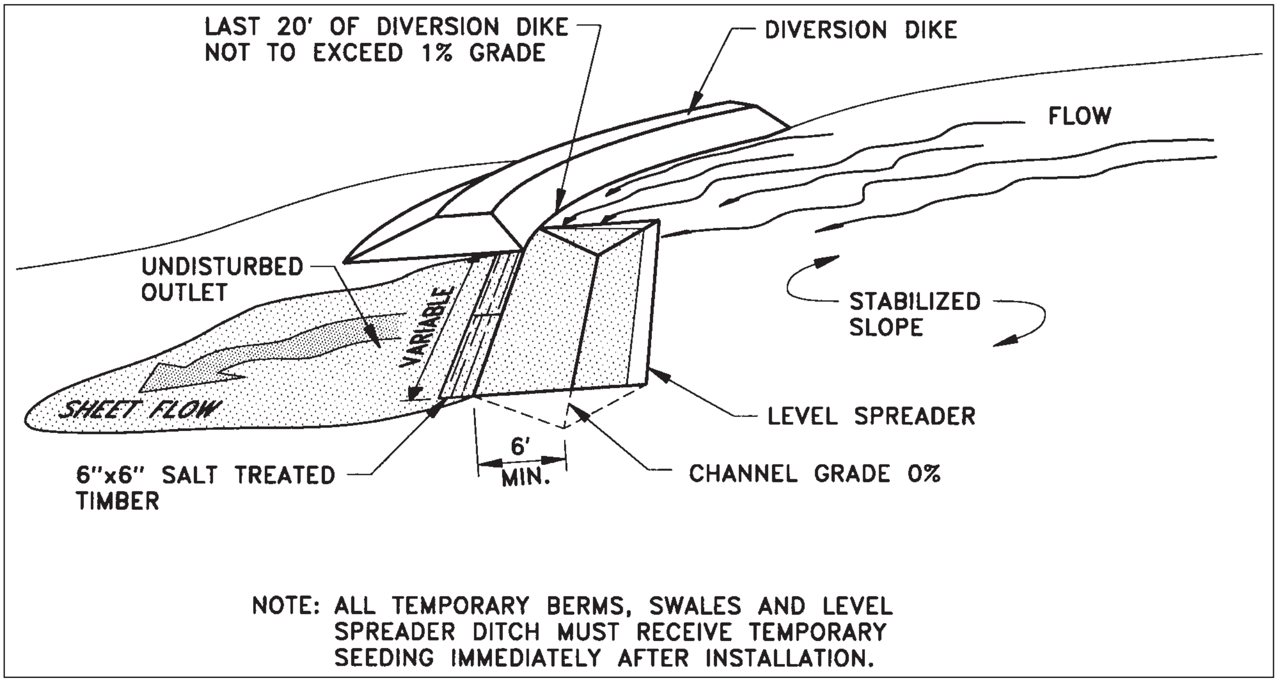


FIGURE 27.13 Level spreader. (*Source: Virginia Erosion and Sediment Control Handbook,* 1992)

becoming too erosive. Steep slopes below the level spreader promote erosion as the sheet flow accelerates downslope. The spreader length is determined by estimating the flow expected from the design storm and selecting the appropriate length from Table 27.5. Furthermore, the design flow determines whether a vegetated or rigid lip should be employed.

Production of uniform sheet flow requires uniform discharge over the lip. Any trash, debris, or sediment accumulation within the level spreader will disturb the production of uniform flow. Frequent inspection and cleaning are necessary for the level spreader to operate effectively.

Coastal Erosion Control Measures

Losses due to erosion are anticipated to grow over the next few decades as coastal areas continue to erode into areas of denser development. Site management by planning development to avoid sensitive coastal land is the most effective coastal erosion control measure. Many states regulate land use along the coast through setbacks, control zones, or a combination of the two. Setback requirements limit building within a specified distance of the shoreline. Control zones regulate a range of activities, including construction or repair of shoreline stabilization structures, public access, and the use or alteration of a dune and other shoreline habitat areas. Acquisition of privately owned lands by the government or nonprofit groups is another means by which to control development in erosion-prone areas. Acquisition can also be used to achieve important community goals like environmental protection and public beach access. However, acquisition has not been widely used due to the high costs of coastal property.

TABLE 27.5 Level Spreader Length for Design Flows

DESIGN FLOW (CFS)	MINIMUM LENGTH (FT)
0–10	10
10–20	20

In an attempt to protect property from erosion, a variety of structural and nonstructural measures have been utilized. Many of these measures provide only temporary protection from erosion and coastal flooding and require ongoing maintenance or repair. Methods of protecting beaches and shorelines from erosion have depended upon efforts to overcome the natural forces at work near the shoreline. Structures such as seawalls, bulkheads, breakwaters, revetments, and groins have been created as barriers against the natural effects of waves, tides, and currents. These structures inhibit the natural functioning beach/dune system. In doing so, they interfere with the onshore-offshore movement of sand and cause increased erosion on adjacent shores by modifying sediment supply or changing wave refraction patterns. Today, traditional structural measures are generally limited to the protection of existing nonconforming structures and include the following:

Seawalls and Bulkheads. Seawalls and bulkheads have traditionally been used to protect development from storm surges and further recession of an eroding shoreline. Seawalls are used primarily to resist wave action. Bulkheads act as retaining walls, keeping the earth behind them stable (see Figure 27.14). While these can prevent the recession of a shoreline, they cannot prevent the erosion of beach areas. Hardening of a shoreline can interfere with the necessary profile adjustments of a beach. A dune can no longer share its sand with a beach. As a retreating beach encounters a seawall or bulkhead, it can no longer draw upon the landward sand supply, exacerbating erosion at the site. Furthermore, as the beach retreats and the seawall or bulkhead is exposed to waves, the seabed in front of the structure is subject to scour. This results in additional erosion, undermining, and eventual failure of the structure. Seawalls and bulkheads also tend to reflect wave energy, which may induce problems elsewhere.

Seawalls and bulkheads can be built in three basic types: as interlocking sheetpiles driven into the ground, as individual piles used to support an aboveground structure, or as a massive gravity construction resting on the shore bottom, supported by its own weight. Bulkheads and seawalls must be of sufficient strength to withstand the forces of waves and wave-carried debris, both in front of the wall and behind it. Water flowing around the wall can cause excessive erosion and scouring, so the flanks of the wall need to be protected.

Breakwaters. Breakwaters reduce erosion by dissipating wave energy offshore and thus reducing transport potential to areas behind the structures. While breakwaters can reduce the erosive impact of waves, they can cause localized accretion in the lee of the breakwater; these features are referred to as *salients.* Breakwaters can be constructed from many different materials including stone, concrete, plastic,

Figure 27.14 Wooden bulkhead for bluff recession stabilization. (Photo courtesy of Brian K. Batten, PhD)

and salvage material such as railroad cars. Many variations exist in breakwater construction: structures can be built submerged, subaerial, continuous or segmented, and detached or attached to shore (see Figure 27.15). Proper placement and design of these structures is achieved through numerical modeling of physical conditions at the site as well as a comprehensive understanding of long-term coastal processes. Improper design can lead to nonfunctional or overfunctional structures. If too much wave energy is attenuated, the salients can accrete out to the breakwaters, effectively forming a groin field and imposing a severe sediment burden on beaches downdrift of the structures.

Revetments. Revetments are structures placed on the banks or bluffs in such a way as to absorb the energy of incoming waves. They are usually built to preserve the existing uses of the shoreline and to protect the slope. Where available, rubble or quarry stone is the most reliable and economical material choice for revetments (see Figure 27.16). Other alternatives include bags filled with a wet sand-cement mixture, concrete blocks or slabs, and gabions. Most revetments do not significantly interfere with littoral drift; however, they limit sediment supply to the system from the protected embankments. These structures do not redirect wave energy to vulnerable unprotected areas, although beaches in front of steep revetments are prone to erosion. In some locales, bank sloping in combination with soil bioengineering techniques is favored over structural revetments.

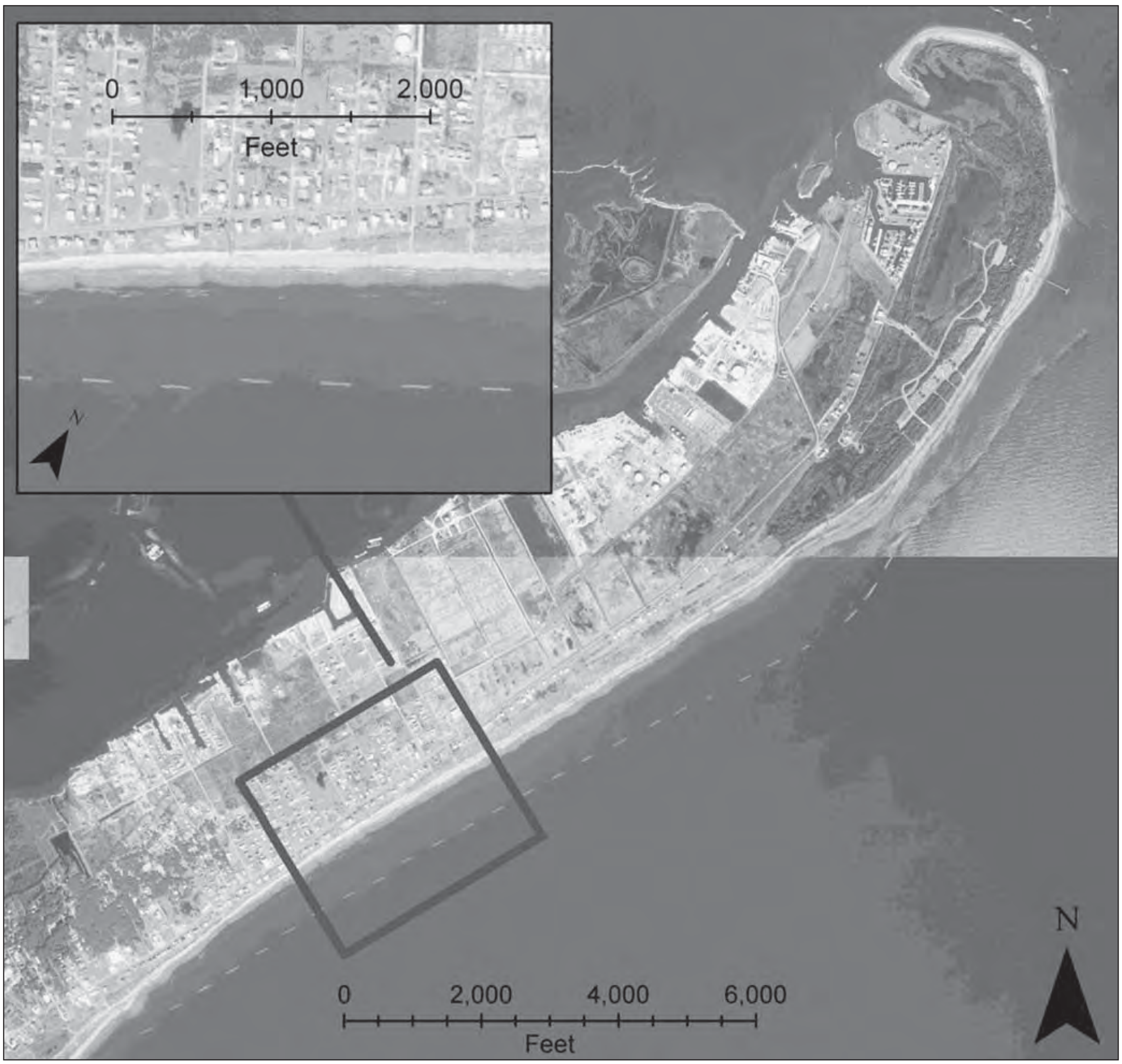


FIGURE 27.15 Segmented detached breakwaters, Grand Isle, LA. (Aerial photograph courtesy of the Louisiana Oil Spill Coordinators Office)

Groins. Groins are used to manage longshore transport of littoral drift to control erosion. Groins are structures that extend perpendicularly from the coastline and are typically constructed in groups called fields (see Figure 27.17). They are most effective where the longshore transport is predominantly in one direction or where their construction will not cause unacceptable erosion of the downdrift shore. Contemporary construction methods usually require prefilling of the groin compartments with sand to minimize downdrift impacts. Groin fields must be carefully designed with respect to height, spacing, extension, and porosity. Groins must extend far enough in the water to retain adequate amounts of sand, but not so long that rip currents develop along them. Rip currents carry sand offshore into deep water, where waves cannot return it to the beach.

Soft Structures. Sandbags and geotextiles can provide a soft structural erosion control solution. Sandbags are usually installed on a temporary basis in front of structures that have been exposed to wave impacts. The bags are left in place until the beach recovers, the structure fails, or a more permanent solution is determined. Geotextiles are often used in the form of a sand-filled tube that is placed in the center of engineered dunes in erosion-prone areas. The tube provides a last line of defense from wave action for landward properties in the event of dune failure. Clay cores are also used in dunes when material is available.

Nonstructural Measures. Nonstructural measures to protect coastal property from erosion include vegetation and replenishment. Natural salt-resistant vegetation provides good protection for the dune system, inhibits both wind and sand erosion, and allows the system to adjust to natural stresses (see Figure 27.18). Removal of existing salt-resistant vegetation from dunes is typically discouraged or prohibited. Sand fencing is another popular method of encouraging dune growth.

Adding fill to beach, either to replace the lost beach materials or to increase the size of an existing beach, can be an economical and effective means of storm protection and erosion mitigation. Beach replenishment (i.e., nourishment) material should resemble the original beach material and be placed to match the natural slope as closely as possible (see Figure 27.19). The design template must account for post-construction adjustment of the material to the equilibrium profile, which is dependent on the grain size of the fill mate-

FIGURE 27.16 Stone revetment for shoreline stabilization—Montauk, NY. (Photo courtesy of Brian K. Batten, PhD)

FIGURE 27.17 Rubble-mound groin (ground photo). (Photo courtesy of Brian K. Batten, PhD)

FIGURE 27.18 Vegetative dune stabilization. (Photo courtesy of Brian K. Batten, PhD)

FIGURE 27.19 Example of beach nourishment at Kure Beach, NC. (Image courtesy of U.S. Army Corps of Engineers)

rial. This calculation is essential, as the postadjustment beach is narrower than the constructed template. Material is typically dredged from offshore deposits, pumped onshore, and then manipulated into the design template by bulldozer. When offshore sand resources are limited or not cost effective, material can be trucked in from upland sources.

This section has presented a general overview of coastal erosion and structures. For more comprehensive descriptions and technical information on coastal processes and design guidance for shore protection structures, please refer to the Coastal Engineering Manual (U.S. Army Corps of Engineers, 2002).

SEDIMENT CONTROL BEST MANAGEMENT PRACTICES

Sediment-laden runoff is controlled on construction sites by either (1) directing the flow through perimeter filtering devices or (2) retaining it on-site in impoundment devices that allow adequate residence time for particle settlement. Sediment filters, such as silt fence and inlet protection, are used to filter sediment from runoff. Impoundment devices are typically sediment traps or basins; the distinction depends upon the acreage draining to the facility, the facility design, and whether they are temporary or permanent. For example, in Maryland, facilities with drainage areas less than 10 acres require sediment traps, while larger drainage areas require the use of sediment basins. Sediment basins are frequently stormwater management ponds that are modified for use as a sediment detention facility during construction and, after permanent stabilization is complete, converted to a stormwater management pond.

Sediment Filters

Filtering controls (sediment barriers) intercept and filter both sheet flow runoff as well as small volumes of concentrated flow. They can be used as stand-alone controls or with sediment traps to enhance their effectiveness. Synthetic filter fabric, stones, or straw bales are typical filtering devices.

Silt Fence. Filter fabric fence, commonly referred to as *silt fence* (Figure 27.20), is placed along or parallel to a contour (i.e., perpendicular to the sheet flow direction) to intercept upstream sheet flow. The distance limitations for the use of filter fabric fence are shown in Table 27.6. Filter fabric fence should not be used in situations where it will intercept concentrated flows or act as a velocity check in ditches or swales. Filter fabric cloth is made of synthetic fabric (polymer) that has a specified flow rate and tensile strength. The filter fabric cloth is attached to vertical posts and embedded in a trench at the bottom to keep the runoff from undermining the fabric. For added stability, the filter fence can be attached to wire support fence, thereby allowing a reduction in the tensile strength of the fabric. To maintain its effectiveness, silt fence should be inspected regularly and after each rainfall event; any accumulated sediment must be removed.

When the length of flow or steepness of the slope contributing to conventional filter fabric fence is too great, many permitting agencies allow the use of filter fabric cloth supported by chainlink fence, or *super silt fence* (Figure 27.21), as an acceptable alternative. The distance limitation for using super silt fence is reflected in Table 27.7. The cost of super silt fence is higher than that of silt fence, but the use of super silt fence in certain circumstances may actually be more cost effective in areas where sediment traps would otherwise be required or damage to environmentally sensitive land may otherwise not be avoidable. Super silt fence is ideal for steep slopes where space is at a premium. As with silt fence, super silt fence should be inspected regularly and after each rainfall event to maintain its effectiveness; any accumulated sediment must be removed.

Straw Bale Dikes. Staked, straw bale dikes have long been used as a barrier to trap sediment. The bales are typically placed in a 4-inch-deep trench on the contour and staked to the ground with wooden stakes or reinforcing bars. The ends are tightly butted against one another to prevent gaps through which runoff can seep. Typically, this filtering system is placed at the toe of relatively short slopes. The use of straw bale dikes *is not recommended* as a primary sediment control device. Straw bale dikes clog and deteriorate rapidly and require frequent maintenance. In addition, silt fence is more efficient in terms of filtering capabilities and has a significantly reduced flow-through rate. The filtering efficiency of straw is approximately 67 percent, while filter fabric has an efficiency of nearly 97 percent. The flow rate for straw is 5.6 gal/ft^2/min compared to filter fabric, which is about one-tenth of that value.

Inlet Protection. This filtering method can be used at both curb and grate inlet openings. Inlet protection devices typically use stone and filter fabric around drainage inlets to filter the sediments draining to the structures. This method of storm inlet protection is used only for small drainage areas—usually an acre or less. Care should be taken when protecting curb inlets that have been installed on a grade. To ensure that the flow does not bypass the inlet protection device, an asphalt berm or some other flow diversion device may be required in order to direct flow to the inlet. Other types of

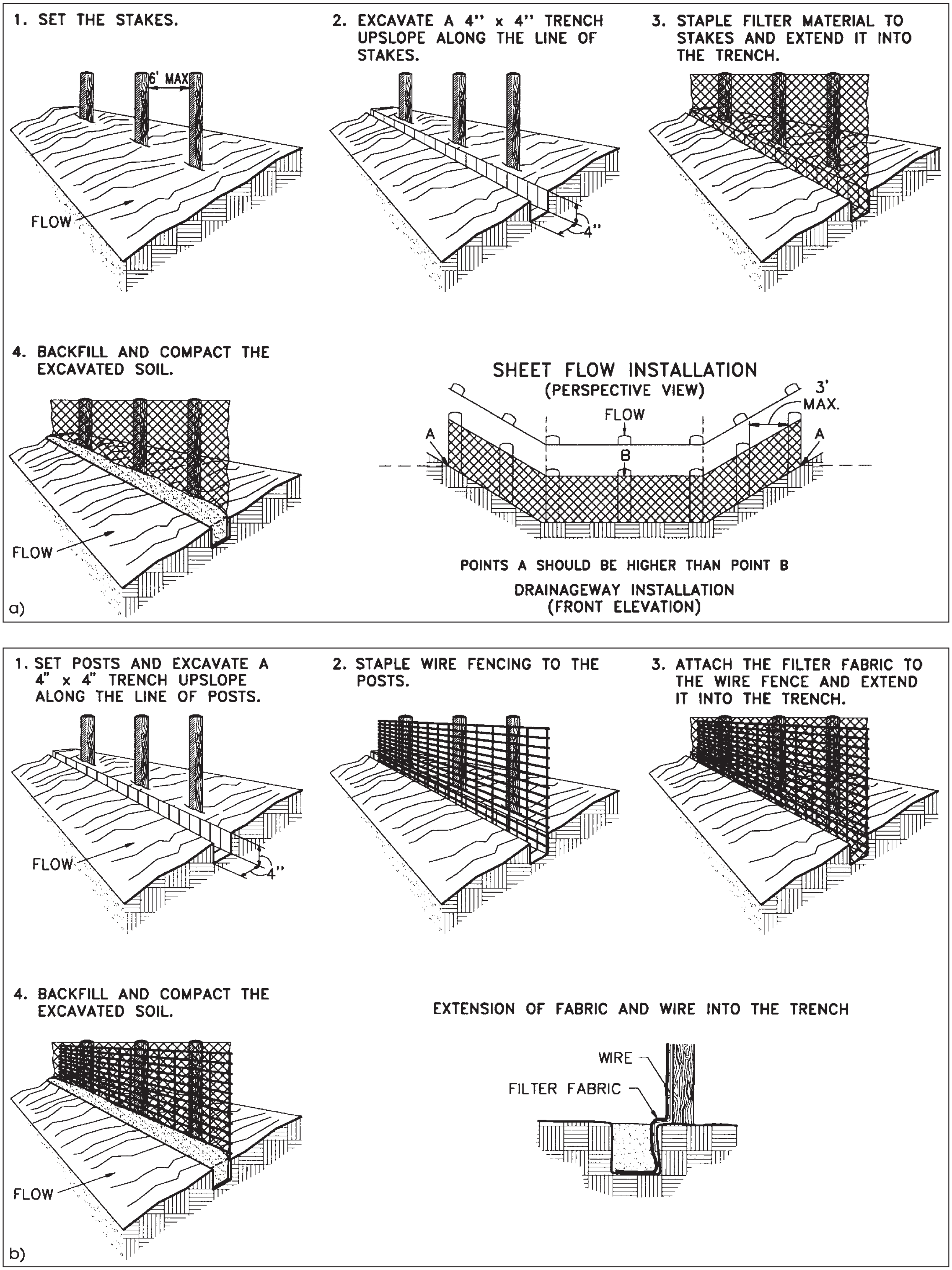


FIGURE 27.20 Construction details for filter fabric fence. (*Source: Virginia Erosion and Sediment Control Handbook*, 1992)

TABLE 27.6 Filter-Fabric Fence Design Constraints

Slope Steepness	Maximum Slope Length (ft)	Maximum Silt Fence Length (ft)
Flatter than 50:1 (2%)	Unlimited	Unlimited
50:1 to 10:1 (2–10%)	125	1000
10:1 to 5:1 (10–20%)	100	750
5:1 to 3:1 (20–33%)	60	500
3:1 to 2:1 (33–50%)	40	250
>2:1 (>50%)	20	125

inlet protection include a yard inlet protection device. Figure 27.22 shows variations of inlet protection. To maintain its effectiveness, inlet protection devices must be inspected after each rainfall event. If water ponds on the inlet protection device longer than 48 hours, accumulated sediment must be removed and the filter fabric replaced, since the device is most likely clogged and not effective.

Sediment Storage Measures

Sediment Basins. Sediment basins are typically designed to impound sediment-laden runoff by reducing the velocities and turbulence of the runoff to levels where the majority of the suspended particles are given an opportunity to settle out by gravity. A sediment basin consists of a strategically placed embankment that takes advantage of the natural terrain to create an impounding area. Basins may be excavated, but they cannot be located in fill. The basin contains an outlet structure that releases the treated runoff at a slow rate to allow for settlement of suspended solids. The design of sediment basins is similar to the design of stormwater management ponds. A riser (or control) structure is designed to retain certain volumes and convey larger storms usually 10 years and above. In some cases, the sediment basin contains an emergency spillway to allow the larger storms to pass through the facility unimpeded. Depending on the jurisdiction and the size of the watershed to the basin, either rational method or SCS hydrology may be used to determine contributing design flows.

Typically, the outlet structure is composed of a vertical pipe with several small-diameter holes near the bottom. This pipe is open at the top to allow for excess overflow of intermediate storms. The size and elevation of the holes control the release rate of the impounded water. Outlet structures other than the perforated vertical pipes are used for sediment basins that are intended for conversion to permanent facilities. Such facilities tend to have an outlet structure more elaborate and aesthetically pleasing such as a multistage weir.

The size of a sediment basin is measured by its storage volume. The required storage volume is a function of the amount of disturbed area draining to the facility. Sizing a sediment basin depends on local municipalities' design standards, which are developed according to the regional conditions. In some cases, determining the volume of the basin may be as uncomplicated as applying a single constant to the drainage area (e.g., 3600 ft^3 or 134 yd^3 of required storage volume per drainage acre, as in Maryland). This design parameter approximates an upper limit for the amount of sediment expected to be delivered to the facility for the design storm. The assumption here is that the design storm erodes a constant amount of sediment. This blanket value does not consider the soils or topographical features that vary from site to site nor the daily variations of the site conditions. In other cases, sizing the basin requires a detailed analysis of the on-site soils and their particle size distribution. This information is used with the USLE or discrete particle settling theory to set the basin size.

Discrete Particle Settling Theory. A discrete particle is one that does not change in size, shape, or weight as it settles. The discrete particle settling theory describes the settling behavior of particles in an ideal basin in quiescent water. Particle settling, in such ideal conditions, depends on the properties of the fluid and the particles' characteristics. Any interaction between the particles within the fluid is assumed to be negligible.

A particle settling in a quiescent fluid accelerates under the influence of gravity until the driving force of gravity is balanced by the resisting drag force. At this point, the particle has achieved a terminal velocity and, as such, remains constant during the remainder of the falling distance. The terminal settling velocity v_S for a spherical particle is:

$$v_S = \sqrt{\frac{4g(\rho_P - \rho_W)d_P}{3C_D\rho_W}} \tag{27.2}$$

where ρ_p = density of the spherical particle, ρ_W = density of water, g = acceleration due to gravity, and C_D = coefficient of drag for the particle.

The drag coefficient C_D is approximated by

$$C_D = \frac{24}{N_R} \quad \text{for} \quad N_R < 1 \tag{27.3}$$

$$C_D = \frac{24}{N_R} + \frac{3}{N_R} + 0.34 \quad \text{for} \quad N_R \geq 1$$

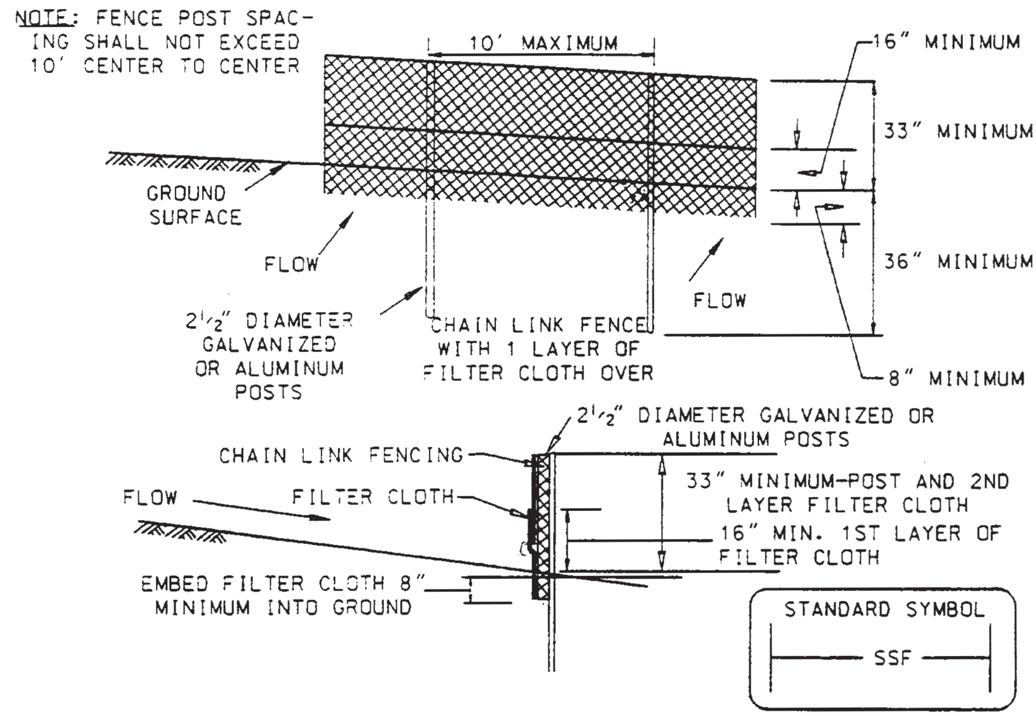
where N_R, the dimensionless Reynolds number, is

$$N_R = \frac{v_S d_P \rho_W}{\mu} \tag{27.4}$$

with μ = the absolute viscosity of water. Note that when N_R is less than 1, the settling velocity for a sphere reduces to Equation 27.5:

$$v_S = \frac{g(\rho_P - \rho_W)d_P^2}{18\mu} \tag{27.5}$$

DETAIL 33 – SUPER SILT FENCE



Construction Specifications

Fencing shall be 42 inches in height and constructed in accordance with the latest Maryland State Highway Details for Chain Link Fencing. The specification for a 6 foot fence shall be used, substituting 42 inch fabric and 6 foot length posts.

1. The poles do not need to set in concrete.

2. Chain link fence shall be fastened securely to the fence posts with wire ties or staples.

3. Filter cloth shall be fastened securely to the chain link fence with ties spaced every 24" at the top and mid section.

4. Filter cloth shall be embedded a minimum of 8" into the ground.

5. When two sections of filter cloth adjoin each other, they shall be overlapped by 6" and folded.

6. Maintenance shall be performed as needed and silt buildups removed when "bulges" develop in the silt fence.

U.S. DEPARTMENT OF AGRICULTURE	PAGE	MARYLAND DEPARTMENT OF ENVIRONMENT
SOIL CONSERVATION SERVICE	H - 26 - 3	WATER MANAGEMENT ADMINISTRATION

FIGURE 27.21 Construction details for super silt fence. (*Source:* USDA, Soil Conservation Service, Maryland Department of Environmental Water Management Administration, 1994)

TABLE 27.7 Super-Silt-Fence Design Criteria

Slope Steepness	Maximum Slope Length (ft)	Maximum Fence Length (ft)
0 to 10:1 (0–10%)	Unlimited	Unlimited
10:1 to 5:1 (10–20%)	200	1500
5:1 to 3:1 (20–33%)	100	1000
3:1 to 2:1 (33–50%)	100	500
>2:1 (>50%)	50	250

which is Stoke's law for the settling velocity of a sphere in laminar flow. This can be reduced to

$$v_S = 2.8 d_P^2 \tag{27.6}$$

where v_S is in fps and d_P is in mm, assuming the specific gravity of the particle = 2.75 and a water temperature of 70°F.

An idealized rectangular settling basin (Figure 27.23) consists of four zones: the inlet zone, the removal zone, the outlet zone, and the settling zone. The length L is the distance between the inlet and outlet zones, H is the depth of the settling zone, and W is the width of the basin. Under such idealized conditions the incoming flow Q_i is steady and constant for the width of the basin. Particles within the incoming flow move horizontally through the basin with a horizontal velocity $v_h = Q_i/(WH)$. The vertical velocity component is the settling velocity v_S.

The design of an effective settling basin relies on the fact that an incoming particle travels the vertical height H and settles out before it travels the horizontal length L and is discharged. At or below the height H, the particle is in the settling zone and is considered removed from suspension. The time T_L for the particle to travel the horizontal length L of the basin is given as

$$T_L = \frac{L}{Q_i (W \times H)} \tag{27.7}$$

The time to travel the height H is given as

$$T_H = \frac{H}{V_S} \tag{27.8}$$

Therefore, the minimum time needed for the particle to settle out of suspension occurs when the vertical time is equal to the horizontal time for the given particle. Equating Equation 27.7 to Equation 27.8 shows that v_S is:

$$\frac{L}{Q_i (WH)} = \frac{H}{v_S} \tag{27.9}$$

$$v_S = \frac{Q_i}{LW} = \frac{Q_i}{A_S}$$

Alternatively, the optimal surface area of the tank needed to capture particles with a settling velocity of v_S and greater occurs when $A_S \geq Q_i/v_S$, where A_S is the surface area of the settling zone. Hence, for ideal conditions, the design parameters of an effective settling basin do not include depth and volume. For all particles (with settling velocities of v_S and greater) entering the tank with the given discharge (Q_i), the basin efficiency is determined by the surface area A_S relative to the discharge for steady state conditions.

To summarize, the basic assumptions for discrete particle settling theory are:

1. Rectangular basin configuration
2. Constant inflow at one end
3. Constant horizontal and vertical velocity of particles
4. Same concentration of suspended particles, of each size, at all points in the vertical cross section at the inlet
5. Particle settlement unhindered by other particles
6. Permanent removal of a particle from suspension when it reaches the bottom of the settling zone

Trap Efficiency. Trap efficiency is the ratio of the amount (by weight) of sediment retained in a trapping facility to the total amount of sediment entering the facility. This efficiency is a function of the incoming sediment characteristics and the rate of flow through the facility. The rate of flow through the facility depends on the amount of inflow, available storage, and outflow rate. In turn, outflow rate depends on the configuration and the location of the outlet.

Settling behavior of particles depends on the size, shape, and density of the particle. The wide spatial variation of soil characteristics in a given region, coupled with the mixing of soil layers during land-disturbing activities, produces a varied distribution of particle sizes entering a trapping facility. Additionally, rainfall intensity and antecedent moisture conditions affect the type and amount of sediment eroded. Hence, trap efficiency can fluctuate due to the variation of particle size, shape, and density distribution.

Trap efficiency, as determined through discrete particle settling theory, is based on the particle size distribution of the sediment entering the facility. In theory, the basin is sized to remove all particles with settling velocities equal to or greater than the design particle size. A particle size distribution curve of the incoming sediment provides an estimate of the trap efficiency. For example, if the design particle size is 200 μm and the particle size distribution curve indicates that 60 percent of the sediment entering the facility is equal to or larger than 200 μm, the trap efficiency is approximately 60 percent. Note that this method of determining trap efficiency assumes that all particles entering the facility have the same density and behave as spherical particles during settling. Because of

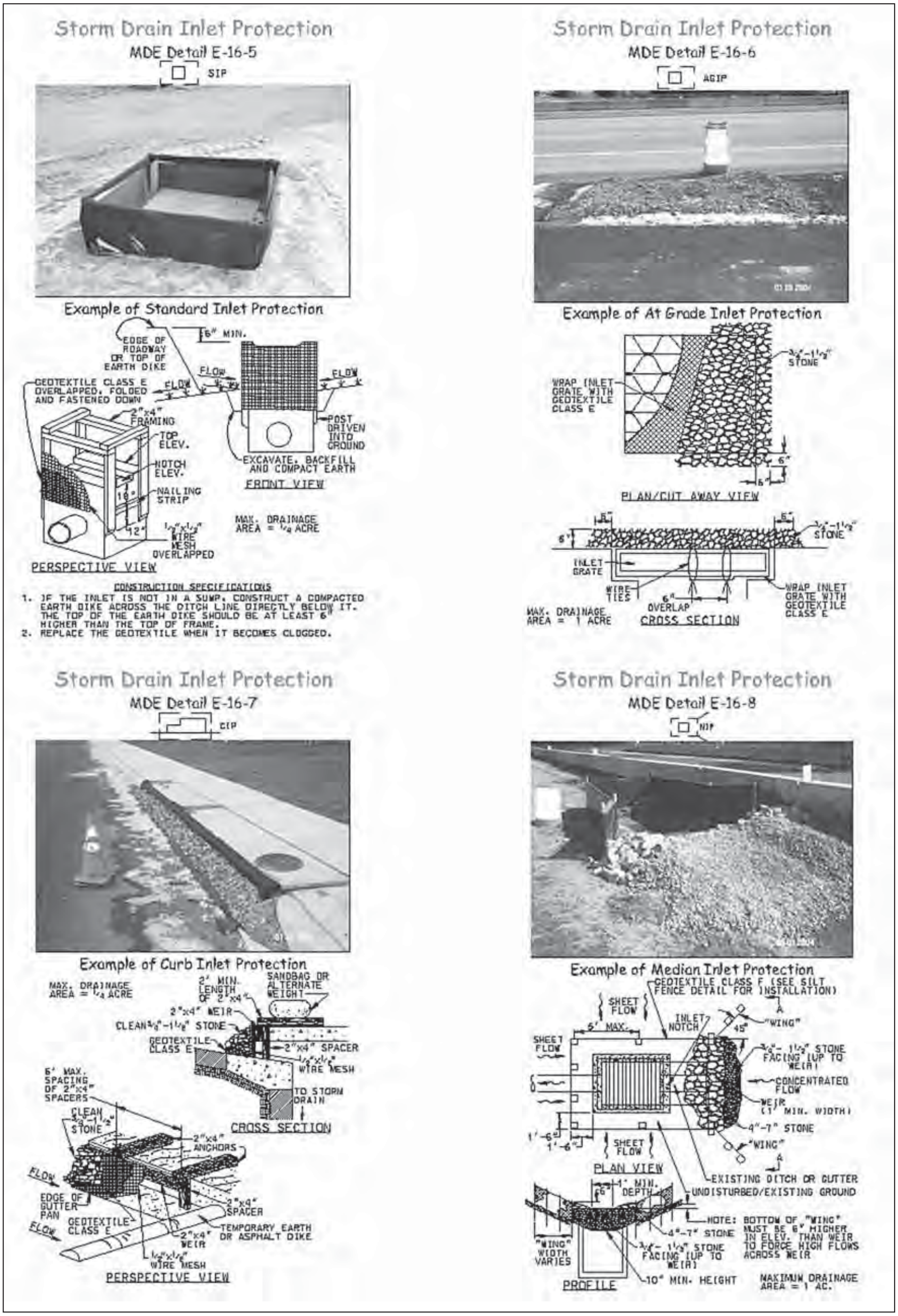


FIGURE 27.22 Inlet protection. (MDSHA/MDE—Field Guide for Erosion and Sediment Control)

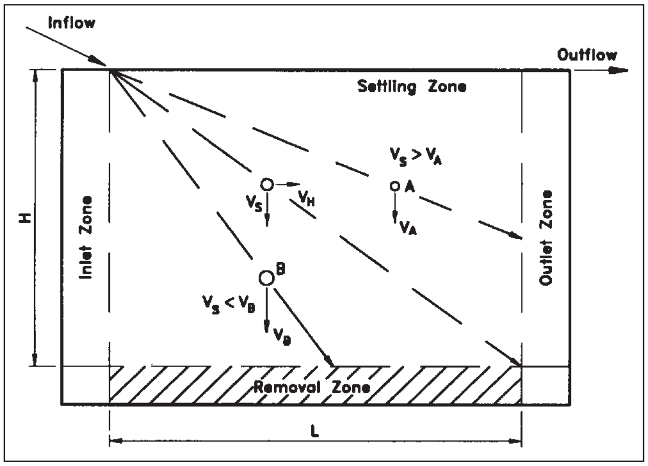


FIGURE 27.23 Idealized rectangular settling basin.

this assumption, this concept slightly underestimates the trap efficiency, since some particles with a settling velocity greater than the design particle size will be retained.

An empirical curve for trap efficiency, proposed by Brune, is based on a study of 44 reservoirs throughout the United States. The curve (Figure 27.24) relates trap efficiency as the ratio of reservoir capacity to annual inflow. Because of the easily obtainable parameters of reservoir capacity and annual inflow, it is perhaps the model most widely used in practical design.

Boysen's Method. Sizing a trapping facility for a predetermined efficiency depends on the design philosophy that one is willing to accept. An alternative to using discrete particle settling concepts to size a settling basin is a method proposed by S.M. Boysen (1974). Boysen's method uses Brune's curve and the universal soil loss equation for development of the urban sediment yield equation.

Boysen's equation expresses off-site sediment yield caused by urban construction as

$$\begin{aligned}&\text{Sheet and rill erosion} + \text{gully erosion}\\&\quad - \text{sediment deposition} - \text{sediment trapped}\\&\quad = \text{off-site sediment yield (in tons)}\end{aligned} \tag{27.10}$$

The basic assumptions for the development of this method are:

1. The USLE is applicable to predict sheet and rill erosion.
2. Gully erosion is prevented by on-site control measures and therefore is assumed to be zero.
3. Sediment deposition before reaching the trapping facility is assumed to be zero.
4. Brune's curve for trap efficiency is applicable.

If the USLE (Equation 27.1) predicts the on-site eroded sediment yield and *TE* is trap efficiency, then

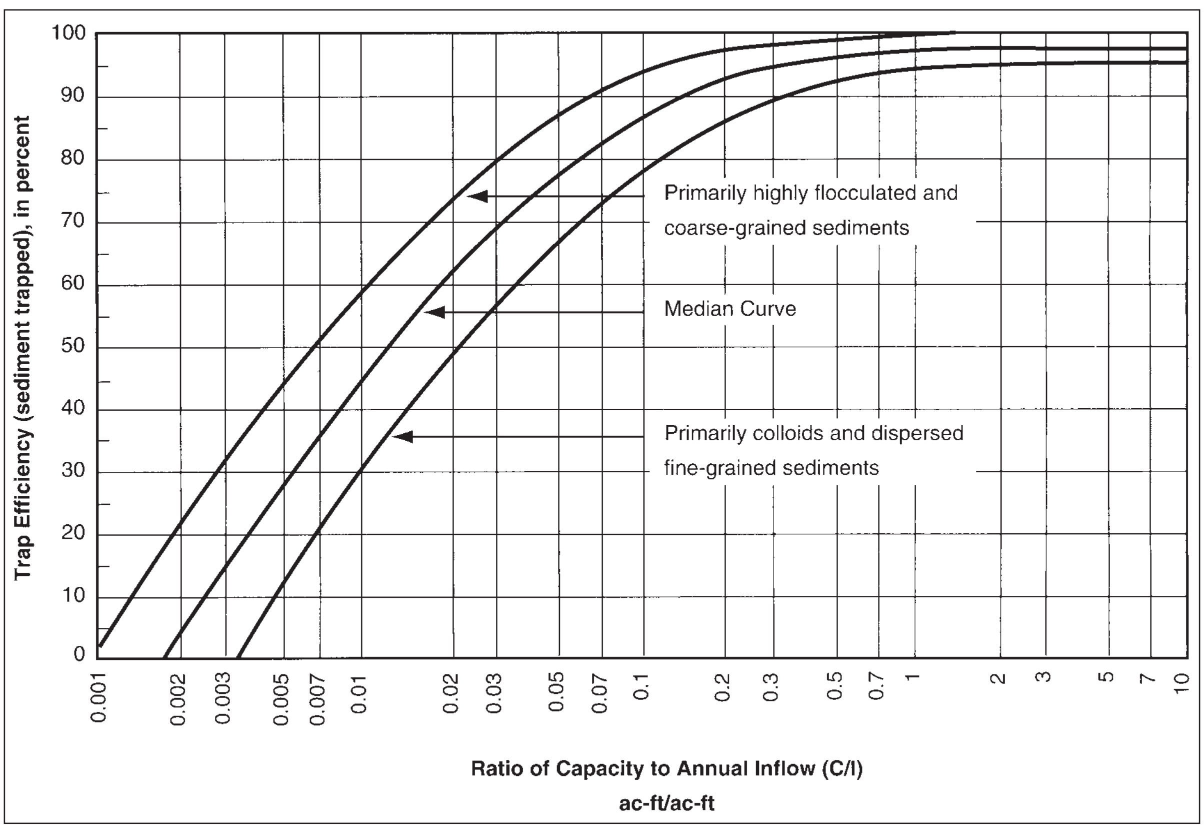


FIGURE 27.24 Trap efficiency of reservoirs. (*Source:* Brune, 1953)

$$\text{Sediment trapped} = (R \times K \times (LS) \times C \times P) * (TE) \quad (27.11)$$

and the off-site (i.e., beyond the sediment basin) sediment yield can be written as

$$(R \times K \times (LS) \times C \times P) * (1 - TE) = \text{Off-site Sediment Yield} \quad (27.12)$$

Assume that a prescribed maximum value limits the sediment yield allowed at a site. If the site erosion is below this value, no erosion controls will be necessary. If the site erosion, as determined by the USLE, exceeds this prescribed upper limit then on-site erosion control measures are necessary. The objective in the design of the on-site control measures is to set the trap efficiency at the difference between the actual eroded sediment and the allowable sediment yield limit.

Limiting off-site sediment yield to some maximum allowable value is expressed by rewriting Equation 27.11 as:

$$\frac{(R \times K \times (LS) \times C \times P)}{\text{Allowable Sediment Yield}} = \frac{1}{(1 - TE)} \quad (27.13)$$

where the left side of the equation is shown as the ordinate on Figure 27.25. The abscissa of the graph is the values of capacity-inflow ratio from Brune's curve converted to cubic yards of capacity per 1 inch of runoff. Brune's curves are redrawn to correspond to the units of the graph of Figure 27.25.

As indicated, either the discrete particle settling theory or Boysen's method is an acceptable methodology to determine the size and storage volume for a sediment pond. Note that the design is incomplete, since hydrologic routings should be done to determine the size for the runoff volume. This entails the design of outlet structures and emergency spillways as well as the determination of the overall depth based on the design storms selected for the hydrologic analysis.

Drawdown Time. One assumption of the discrete particle settling theory is that the settling basin remains relatively full. Since some sediment traps are completely dewatered between storms, the settling behavior of the particles will not be as prescribed by the discrete particle settling theory. This will negatively affect the efficiency of the trapping facility.

The effectiveness of a sediment basin is enhanced if it remains relatively full over a period of time to establish quiescent conditions, which allow the sediment particles to settle out. The recommended time it takes for a basin to dewater is 6 to 24 hours. As a result, the volume of the sed-

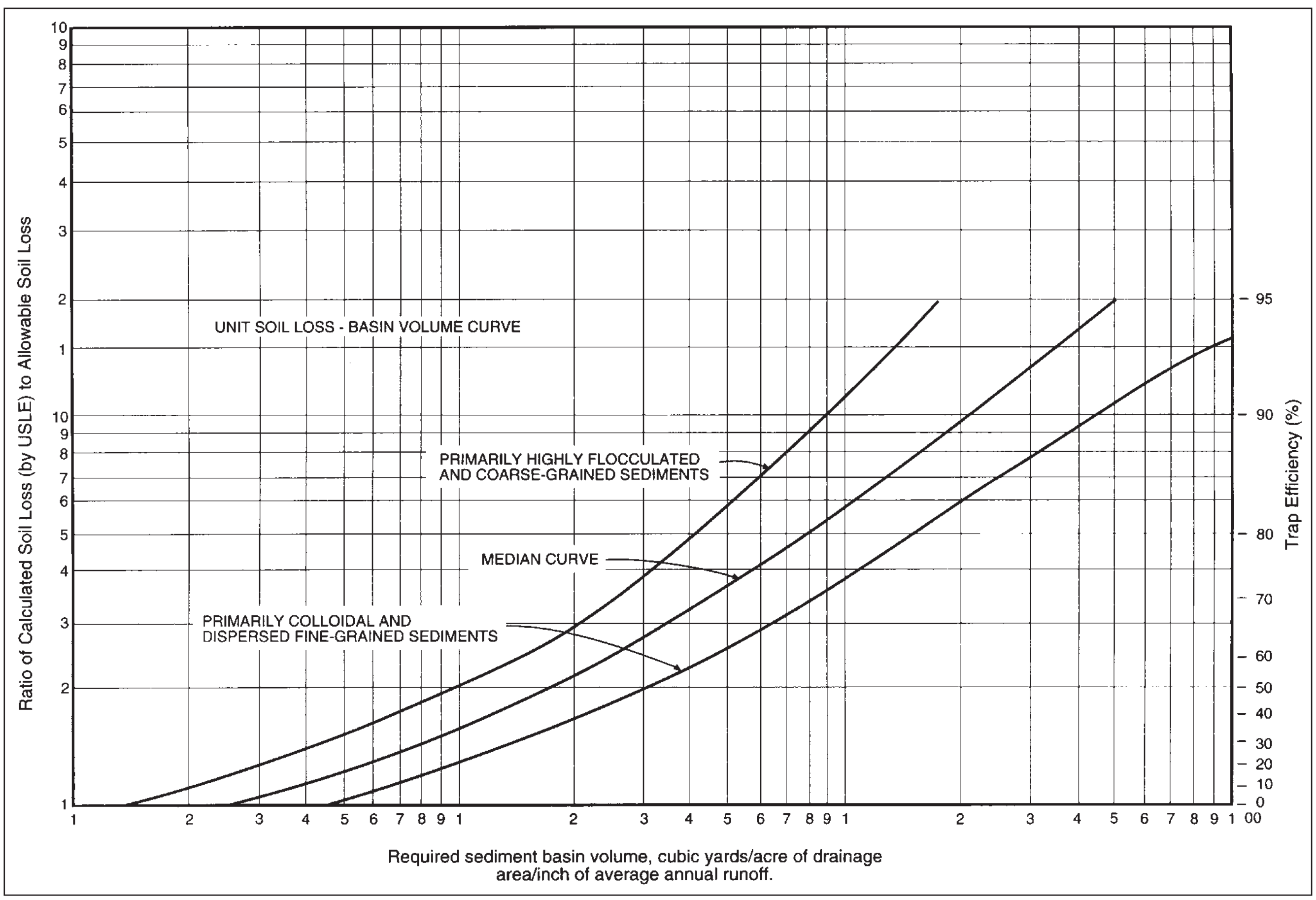


FIGURE 27.25 Sediment basin volume versus ratio of calculated soil loss to allowable soil loss. (From Boysen, S.M. *Predicting Sediment Yield in Urban Areas.* Proceedings of National Symposium on Urban Rainfall and Runoff and Sediment Control, July 29–31, 1974, Lexington, KY. Reprinted with permission from ASAE)

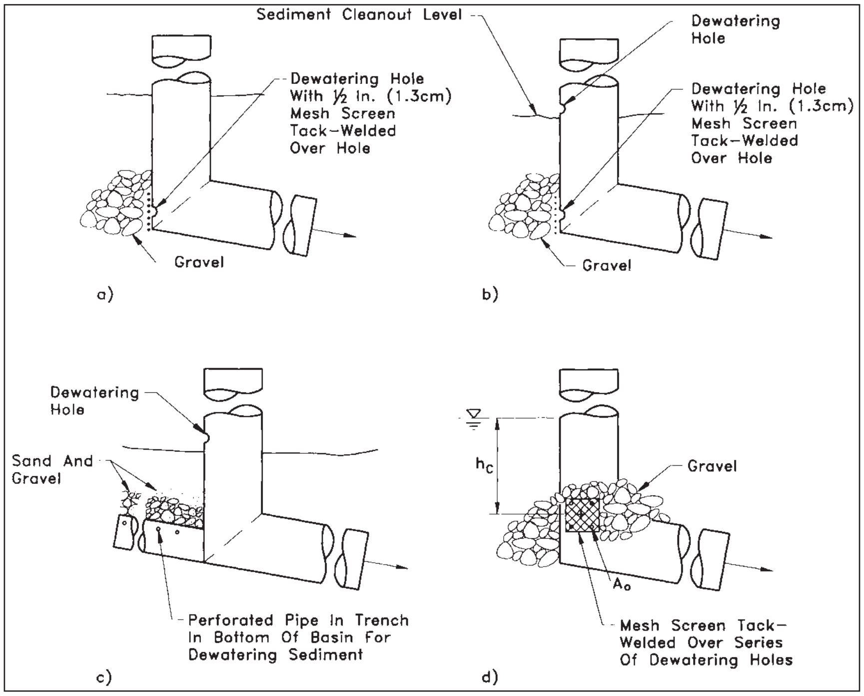


Figure 27.26 Selected riser configurations to dewater a sediment basin. (From Goldman, S., et al. 1986. *Erosion and Sediment Control Handbook.* Reproduced with permission of McGraw-Hill)

iment basin must be sized to adequately store a portion of the design storm for an extended period of time and to safely pass storms of higher design frequencies.

Drawdown time for a basin is found by using the orifice equation to determine the outflow discharge. The orifice equation is used to calculate the flow through a small opening (orifice) for a given headwater. The orifice equation is:

$$Q = C_d \times A_O \sqrt{2gh_C} \tag{27.14}$$

where C_d = coefficient of discharge (≈0.60 to 0.70), A_O = area of the orifice, g = acceleration due to gravity, h_C = distance from the centerline of the orifice to the water surface, and Q = discharge through the orifice.

In sedimentation theory, the mean hydraulic detention time is defined as the discharge divided by the volume, $T = Q/V$. Using the orifice equation and the definition of the mean hydraulic detention time, the time T to dewater a sediment basin is:

$$T = \frac{A_S \sqrt{2h_C}}{A_O A_D \sqrt{g}} \tag{27.15}$$

Perforated pipe outlet structures have several different configurations of holes, as shown in Figure 27.26. Various configurations range from a single hole to several holes at different elevations. Usually the holes are covered with wire mesh screen with gravel piled against the screen to prevent clogging by debris. The gravel, which also acts as a filter, can affect the flow through the orifice(s). Equations 27.14 and 27.15 assume that this effect is negligible. If a cluster of holes is used instead of a single orifice, h_C is the depth to the centroid of the holes and A_O is the total area of the holes.

Increasing Detention Time with Baffles. Detention time can be increased by increasing the flow path through the basin. This can be done by configuring the basin so that the length-to-width ratio is maximized. The value usually recommended as the lower limit for design purposes is 2L:1W.

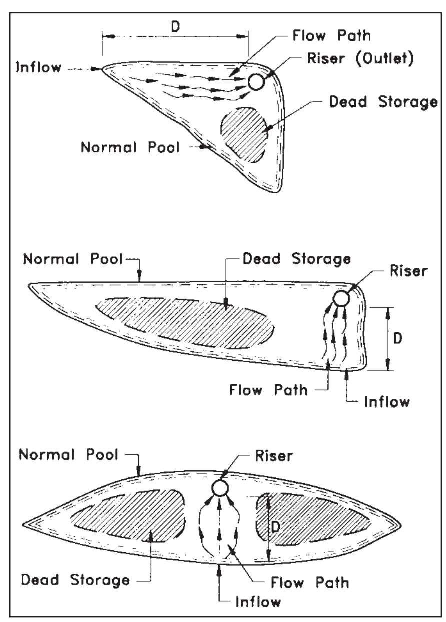


Figure 27.27 Dead storage areas for selected basin shapes. (From Haan, C.T., and B.J. Barfield. 1978. *Hydrology and Sedimentology of Surface Mined Lands.* University of Kentucky Press)

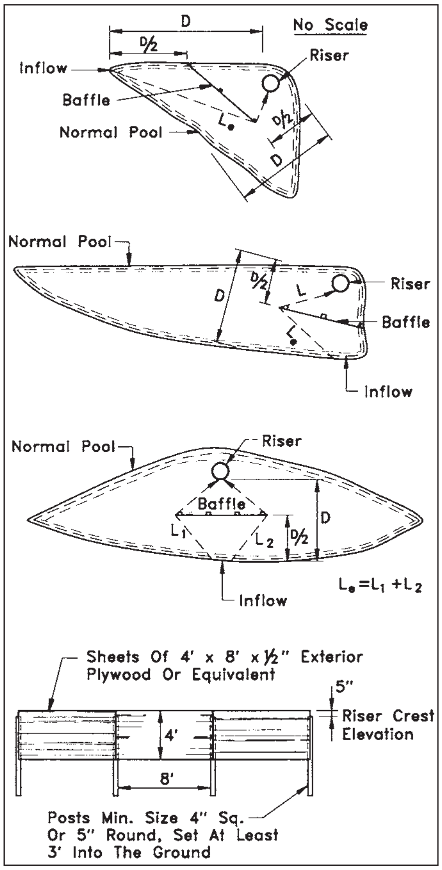


FIGURE 27.28 Recommended placement of baffles. (USDA Soil Conservation Service)

However, this should not be taken to the extreme. A proposed design may size a basin as 5 feet wide by 100 feet long (L:W = 1:20), which, in effect, is more representative of a channel than a sediment basin. A small length-to-width ratio can cause flow-through velocities where the particles have no chance of settling out and the basin loses its effectiveness.

The two main design parameters of a sediment basin are storage volume and detention time. Normally, obtaining the required storage volume is not the problem, even in constricted work areas, since you normally can excavate deeper. If the minimum length-to-width ratio (a controlling parameter for detention time) cannot be met because of site constraints, a solution to the problem of detention time is to install baffles in the sediment basin.

Baffles are devices that actually serve two primary purposes:

1. Baffles enhance the basin shape to increase the length-to-width ratio, thereby increasing the flow path between the inflow and the outflow point. The net result is an increase in detention time.

2. Baffles help to prevent short-circuiting, which is the movement of flow through the basin in such a manner that storage areas are bypassed, resulting in nonuniform distribution of sediment over the bottom area. Dead storage areas, those areas where little or no sediment

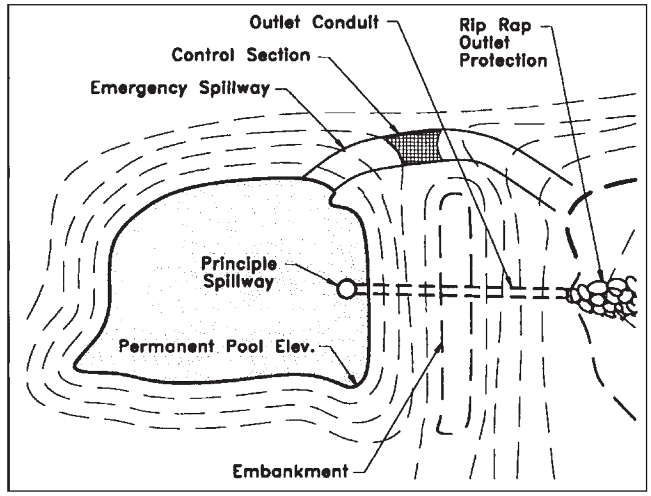


FIGURE 27.29 Schematic plan view of sediment basin.

accumulates, result in reduced trapping efficiency. Baffles minimize dead storage areas by distributing the sediment deposits over a wider area in the basin and increase the efficiency (see Figure 27.27).

Baffles are placed at the midpoint between the primary inflow point and the outflow point. The shortest distance from the inflow point around the baffle to the outflow point is the effective length L_e. The effective width is defined as $W_e = A/L_e$, where A is the surface area of the sediment basin at the normal pool level. The length and orientation of the baffle are modified so that the ratio L_e/W_e is at least 2.0. This minimum ratio applies to all flow paths from inflow points that convey

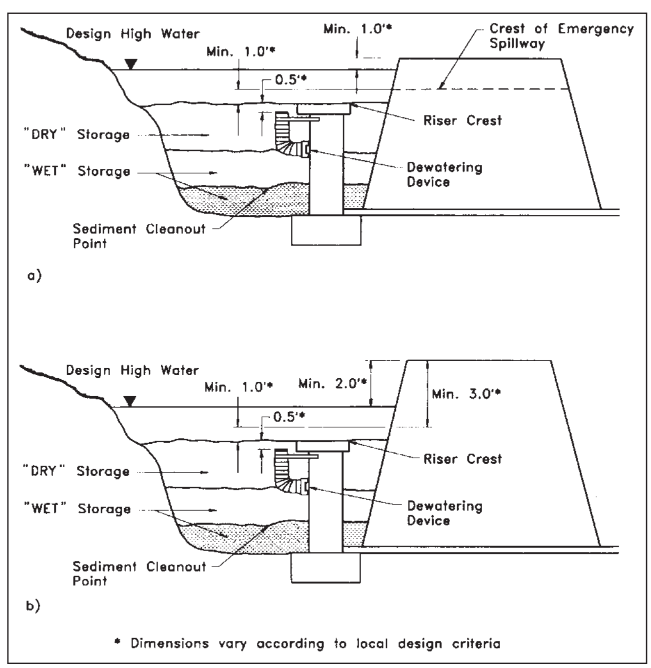


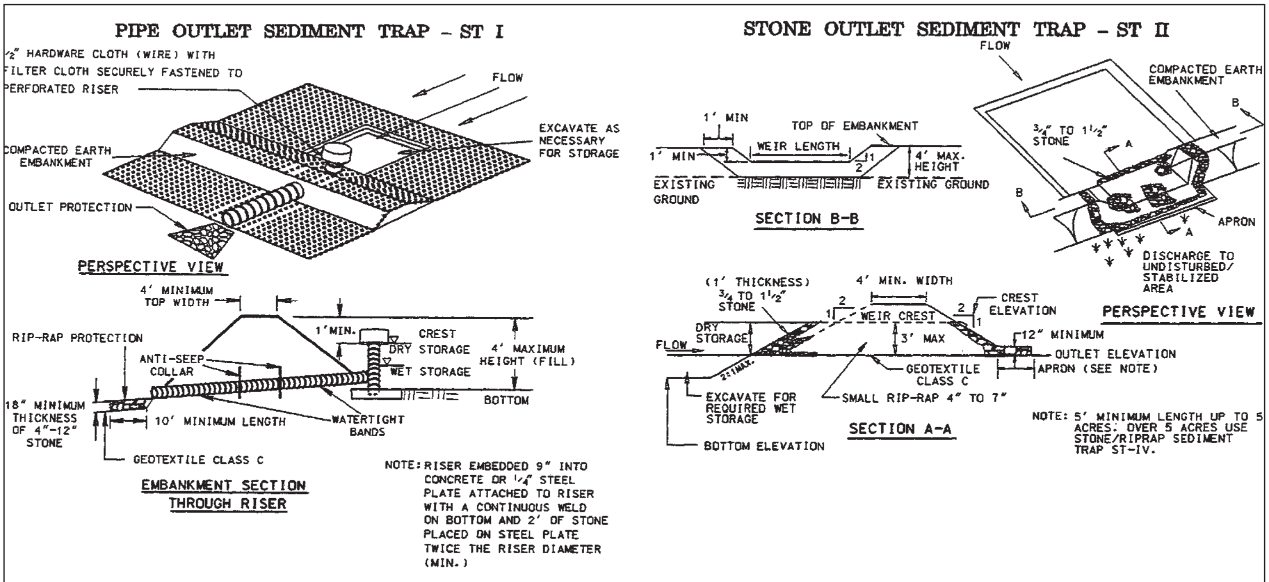
FIGURE 27.30 Schematic elevation view of sediment basin (*a*) with emergency spillway and (*b*) without emergency spillway. (*Source: Virginia Erosion and Sediment Control Handbook,* 1992)

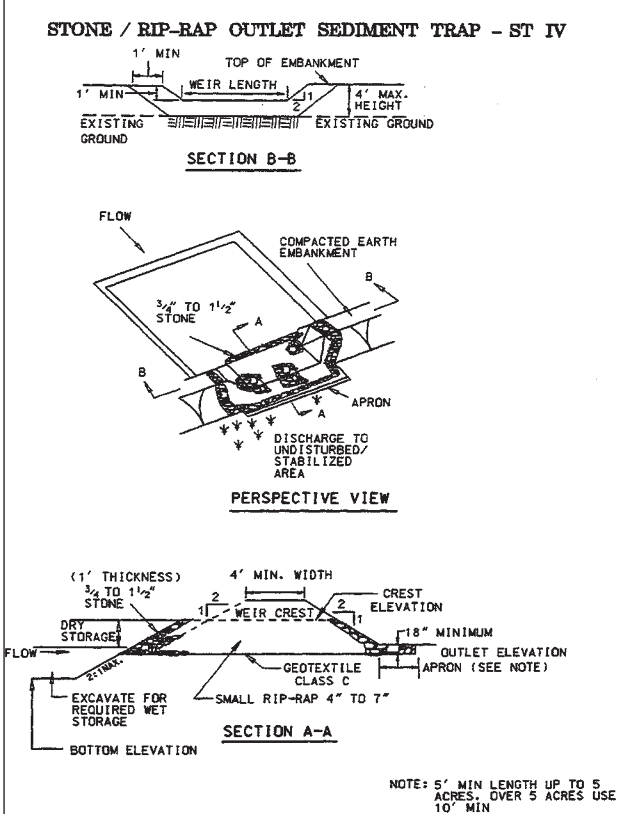
30 percent or more of the peak runoff into the basin. Figure 27.28 shows the recommended location and orientation of baffles for various configurations of sediment basins.

Design Procedure for Sediment Basins. Figures 27.29 and 27.30 schematically show a typical temporary sediment basin layout and its components. The previous discussion focused only on sizing the sediment basin. The complete design involves detailed hydraulic and hydrologic analysis as well as structural considerations. An outline summary of designing a sediment basin follows:

1. Determine the basin sediment volume based on local criteria or an involved analysis of the design particle size and settling criteria.

2. Determine basin location and basin shape based on site conditions. If the length-to-width ratio is less than





Sediment Trap Design Criteria
ST-I, ST-II, ST-IV

DRAINAGE AREA (AC.)	TRAP TYPE*	TOTAL VOLUME (CF)	WET VOLUME (CF)	DRY VOLUME (CF)	MINIMUM DEPTH (FT)	MINIMUM LENGTH (FT)	MINIMUM WIDTH (FT)
1	I/II	3600	1800	1800	2.5	46	23
2	I/II	7200	3600	3600	2.5	68	34
3	I/II	10800	5400	5400	2.5	86	42
4	I/II	14400	7200	7200	3.0	90	43
5	I/II	18000	9000	9000	3.0	101	50
6	IV	21600	10800	10800	4.0	90	46
7	IV	25200	12600	12600	4.0	100	50
8	IV	28800	14400	14400	4.0	105	55
9	IV	32400	16200	16200	4.0	110	60
10	IV	36000	18000	18000	4.0	123	60

*I - PIPE OUTLET (POST), II - STONE OUTLET (SOST), IV - STONE/RIPRAP OUTLET (SROST)

1. The length to width ratio should be 2:1.
2. Minimum length and width dimensions apply to the bottom of the traps.
3. The side slopes will be 2:1 or flatter.
4. If the stone outlet is used in conjunction with rip-rap channel protection then the storage requirement will be 360 cubic feet per acre. If the stone outlet and rip-rap apron are used, the length of the apron will be a minimum of 10'

FIGURE 27.31 Sediment traps. (Maryland Department of the Environment Water Management Administration, 1994)

2:1, consider baffles to establish an adequate length-to-width ratio.

3. Determine the volume of inflow for the design storm (usually 10 years) through hydrologic analysis (TR-55 or other acceptable methods) and then establish the required height of the embankment.

4. Design the principal spillway, taking into consideration the allowable release rate to ensure sufficient detention time for particle settling.

5. Design the emergency spillway (when required) for larger storm events. The design should take into account the hydraulic capacity of the spillway and ensure nonerosive velocities. Many jurisdictions require the emergency spillway to be stabilized with rock outlet protection (riprap) or to be constructed completely in cut.

6. Determine whether additional devices are required such as antiseep collars, antivortex devices, trash rack, dewatering capabilities, and outlet protection.

7. Consider the safety aspect of the facility as with any permanent or temporary impoundment of water. Fence the facility to discourage access.

Sediment Traps. As with sediment basins, sediment traps operate through the combined effects of settling and filtering. Here, the configuration and type of outlet affects the settling and filtering process. Sediment traps are similar to sediment basins in that they are an excavated hole or impoundment created by an earth embankment. However, drainage areas to sediment traps are typically limited to 10 acres or less.

Sediment traps use a variety of material and configurations for their outlet structure, the selection of which depends on local standards. Some localities do not accept certain types of outlet structures due to local conditions or the biases of the local reviewing agency. Outlet structures can be grass aprons, stone or riprap weirs, or even perforated riser pipes. Figure 27.31 shows several of these standards.

The method of sizing sediment traps is typically chosen to maximize settlement of suspended solids. Two primary values are used in sizing sediment traps. The first defines the surface area of the sediment trap per drainage area, and the latter dictates the volume–to–drainage area ratio as the design parameter. As with the basin, the surface area is sized to maximize the length-to-width ratio with the value again recommended as 2:1. Correspondingly, the volume of traps is designed to maximize settlement of suspended solids. In many cases, the design standard for the volume of sediment traps is a single ratio applicable to all sites in a geographic location (e.g., 3600 ft^3 of required storage volume per drainage acre, as in Maryland). Sufficient storage should be provided to allow for adequate settlement and overflow design for larger storm events. Typically, this is done by providing half the volume for wet storage—sediment-laden runoff that pools within the bottom of the trap, while the remaining 50 percent of the trap volume is reserved for overflow runoff and is only temporarily stored for as long as it takes to discharge through the outlet device. This overflow volume is typically referred to as *dry storage*.

For the sediment traps that use weir-type outlets, the recommended crest length in feet is four times the acres of the drainage area that is draining to the facility. If properly designed, the sediment trap can provide adequate protection against downstream erosion problems. Failure of a trap can, in many cases, be attributed to improper installation and maintenance. In many of the traps, the pool is permanent and the outfall is only for overflow of larger storm events. Hence, it is important that the trap be cleaned out after the sediment has accumulated to 50 percent of the wet storage design capacity. If not maintained properly, sediment will eventually accumulate and significantly reduce the efficiency of the sediment trap. Also, the trap should be inspected for damage, especially after large storm events.

AESTHETICS AND SAFETY OF DISCHARGE AREAS

Discharging into Stabilized Areas

Sediment should never be discharged beyond the work area. Sediment can be captured in trapping or filtering devices or even portable sediment tanks or *silt bags* (inlet inserts) for proper disposal. Treated or clean runoff from erosion and sediment control facilities should be directed to an appropriate discharge point or adequate outfall and the aesthetics of this location considered during the course of planning/designing the E&S plan.

Sediment on Pavements

It is imperative to keep silt and sediment off existing pavement. Even though the accumulated sediment dissipates after several rainstorms, such dirty areas detract from the aesthetic value of the site and reduce its attractiveness to potential buyers. Wet soil is slippery and poses safety problems for moving vehicles. Rather than take the risk of personal injury to vehicle occupants or a major cleanup because of the washed-out facility, the engineer should locate the trapping facilities away from pavement and traffic areas.

Construction traffic exiting and entering the site is another source of roadway sediment and frequent public complaints that can result in a visit from the local inspector. The contractor should exercise proper housekeeping practices by sweeping up any debris tracked onto the roadway and using a stabilized construction entrance (Figure 27.32). A stabilized construction entrance consists of a bed of 2- to 3-inch-diameter stone covering an area approximately 50 to 100 feet long and 10 to 30 feet wide. The actual size depends on the type of vehicles using it. This area is designed to collect the mud and sediment clumps accumulating on the wheels of the construction vehicles. If the site is excessively muddy, a wash rack is incorporated into the construction

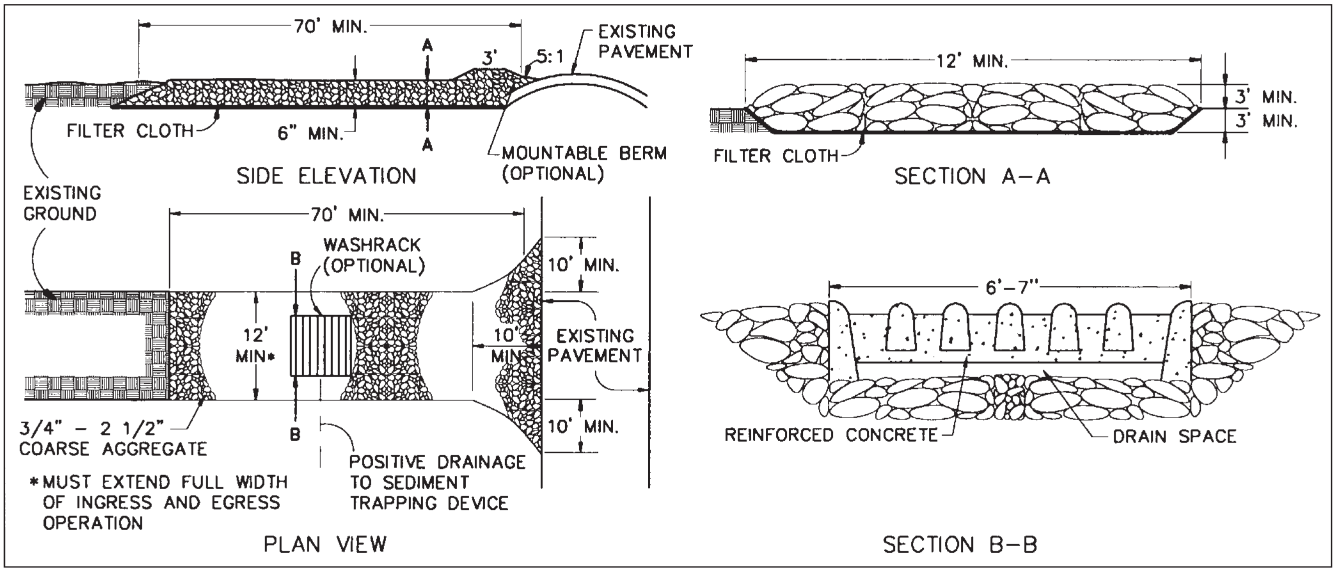


FIGURE 27.32 Typical construction entrance and wash rack (*Source: Virginia Erosion and Sediment Control Handbook,* 1992)

entrance. The wash rack is a raised section of timbers or concrete, partially buried into the stone. The wash rack, which raises the wheels of the vehicle above the stone, allows the wheels to be thoroughly rinsed before exiting the site. A small sediment trap, located on the low side of the wash rack, collects the washed mud. When the stone bed accumulates excessive mud, the stone is replaced.

Dust Control

One problem related to erosion and sediment control, but frequently overlooked, is dust. Wind erosion is one source of dust. On construction sites, traffic, machinery, and other types of related operations (see Table 27.8) are a major source of dust. On dry days, various types of construction operations emit dust that becomes a nuisance to surrounding property and residents. This dust also has an impact on the air quality. According to the *Virginia Erosion and Sediment Control Handbook,* an average value for dust emission at heavy construction sites is 1.2 tons/acre/month. Construction operations can be terminated by the government agency (inspectors) in charge if the dust problem is not promptly addressed.

Dust control is a major concern on sites with soils containing natural asbestos or minerals and geologic formations capable of generating asbestos such as actinolite or, in the mid-Atlantic states, the Orange soil group that contains soils with asbestos-generating minerals. Construction sites with these types of soils present should incorporate specific types of site management measures into the construction sequencing to control dust. These types of measures include minimizing the amount of denuded land by constructing the project in phases and leaving stands of trees around and

TABLE 27.8 Sources of Dust at Construction/Demolition Sites

Construction Sites
Pushing (land clearing and earthmoving)
Drilling and blasting
Batch drop operations (loader operation)
Storage piles (soil and construction aggregates)
Exposed areas
Vehicle traffic on unpaved surfaces
Mud/dirt carryout onto paved surfaces
Demolition Sites
Explosive and mechanical dismemberment (blasting and wrecking ball operations)
Pushing (dozer operation)
Batch drop operations (loading debris into trucks)
Storage piles (debris)
Exposed areas
Vehicular traffic on unpaved surfaces
Mud/dirt/debris carryout onto paved surfaces

(*Source:* U.S. EPA, *Control of Fugitive Dust Sources,* 1988)

TABLE 27.9 Adhesives Used for Dust Control

Adhesive	Water Dilution (Adhesive:Water)	Type of Nozzle	Application Rate Gallons/Acre
Anionic asphalt emulsion	7:1	Coarse spray	1200
Latex emulsion	12.5:1	Fine spray	235
Resin in water	4:1	Fine spray	300
Acrylic emulsion (non-traffic)	7:1	Coarse spray	450
Acrylic emulsion (traffic)	3.5:1	Coarse spray	350

(*Source: Virginia Erosion and Sediment Control Handbook.* 1992)

throughout the grading areas to dissipate some of the wind momentum and act as a barrier. Another measure is the suppression of the dust by mulching or spraying water or adhesive chemicals over the area. Perhaps the most popular is wetting the surface with water. This causes the smaller airborne prone particles to adhere to larger soil masses. However, the rate and frequency of application depend on climatic conditions and the traffic using the roadway. Other types of spray-on materials include synthetic and organic adhesives that, although effective on certain types of soils, are more permanent than water. Consequently, the cost is higher. Chemical stabilization binds soil particles together to form a nonerosive surface crust (see Table 27.9).

Artificial measures such as stabilized earth mounds, fences, and walls can be incorporated into a site to create wind drag and act as barriers to stop the dust from leaving the site. Recommended placement of barriers is perpendicular to prevailing air currents at intervals of approximately 15 times the barrier height (*Virginia Erosion and Sediment Control Handbook*). For those structures intended to be permanent, the judicious placement and timing of construction allows them to serve as dust control barriers as well as site amenities or as zoning ordinance controls for such things as privacy fencing. In the same manner, perimeter trees can be planted; however, only select species may be effective.

CONSTRUCTION SEQUENCING

A familiarity with construction sequencing and techniques aids in the development of a cost-effective erosion and sediment control plan. It is costly for a contractor to interrupt construction operations to change the location of structural measures or to add more. Construction sequencing (i.e., the timely order in which particular items are built) depends on the contractor and the construction procedures, the site itself, sediment and erosion control ordinances, and the type of project.

Establish Perimeter Controls

Construction operations usually begin with the establishment of silt and erosion control measures around the perimeter of the site (or area to be worked on if the site is phased). Site clearing for perimeter controls should be limited to only that minimal area necessary to install the control measure. The perimeter controls retain the sediment on-site while allowing the early grading operations to begin.

Clearing and Grubbing

Clearing and grubbing the site involves removal of trees that cannot be saved, stumps, brush, and other debris. The removal and stockpiling of the topsoil layer in an out-of-the-way location is also included. The stockpiled topsoil is temporarily stabilized with mulch and seed. Silt fence or another suitable sediment control measure is placed around the perimeter of the toe of the stockpiled topsoil. This initial grading operation denudes a large area in a short time, making the area highly susceptible to erosion. The remaining (nonperimeter) first phase erosion and sediment control measures are installed prior to beginning grading operations.

In larger residential developments, clearing and grubbing are initially performed in the street areas and the first few building sites, with roads occurring first. Typically, these building sites are for the model homes that will be used to market the project. In smaller single-parcel commercial areas, the site is almost totally cleared due to the high cost of land and the urgency in getting the site constructed. The limits of clearing and grading should be carefully considered, developed, and monitored during the course of the design process, particularly for projects pursuing green building certification. Credit 5.1 of USGBC's LEED system specifies, for Greenfield sites, strict limits of clearing and grading surrounding site buildings (40 ft), hardscape (10 to 15 ft), utilities (10 to 15 ft), and other constructed permeable facilities (25 ft) in an effort to protect and restore habitat. Adhering to these limits requires a detailed understanding of the development program and careful consideration of construction sequencing and contractor staging, storage, and operational needs. The E&S plan must be coordinated and developed nearly parallel with the grading plan in order to incorporate the recommended working limits effectively.

Mass Grading

After clearing and grubbing, the contractor performs the mass grading of the site. Mass grading is the moving of large quantities of earth to or from the site or within the site itself. On sites where mass grading is necessary, cut and fill areas are large and may not be conveniently localized to optimize haul. Consequently, this operation is performed with larger earthmoving machinery. In many cases, extensive mass grading is necessary on a site due to poor site conditions, not bad planning and design.

Rough Grading

The next operation is the rough grading. Rough grading is the reshaping of the site by moving small volumes of earth so that the site is brought to within ± 0.2 feet of finished grade. This includes preparing the site for basements and foundations, compacting, and generally grading the site to fit the proposed drainage pattern. In areas where subbase and base treatments are required (e.g., streets and foundations), the roughed grades are brought to within ± 0.2 feet of the proposed subgrade elevation. Where fill is to be placed over the proposed utilities, the area is brought to the grade slightly above (± 4 ft to ± 8 ft) the proposed invert elevation of the utility trench. The utility is then installed and backfilled with lighter construction equipment before completing the remainder of the fill operation. This procedure protects the utilities from being crushed by the heavier construction equipment that is utilized for mass grading operations.

The design and location of sediment controls should provide treatment during clearing, mass grading, and rough grading. Should the surface grades not direct the runoff to the erosion and sediment control facilities, the facilities should be relocated or new facilities built to accommodate the new drainage pattern.

Utility Installation

After rough grading operations are complete, the utilities are installed. Usually the deepest utilities and/or those dependent on gravity are installed first. The main concern during this part of the sequence is the storm sewer system. As construction progresses, the site grading evolves such that the overland flow is directed to the storm sewer inlets. As the independent branches of the storm sewer system are complete and made ready to convey runoff, additional erosion and sediment controls are added around the inlets. During the transition from the surface drainage pattern to the proposed subsurface drainage pattern, some of the initial erosion and sediment control measures are phased out as the newer ones are phased in. However, no controls can be removed without the upstream drainage area stabilized *and* the permission of the regulatory inspector.

To facilitate construction, the design should be laid out such that the major utilities (storm, sanitary, and water) can be constructed simultaneously. For example, in town house developments, the sanitary sewer branch lines are placed behind the units whenever possible. If the units are basement walkouts, the sanitary lines need only be minimum depth. This design allows the simultaneous construction of the sanitary lines in the rear, streets and storm drainage in the fronts, and building pads.

Finished Grades

Finally, the site is brought to finished grade. Finished grades are those that are shown on the construction drawings or final grading plans. Final pavement layers are installed on streets and parking areas and the landscape grading is done. Areas around buildings, yards, and planting areas are brought to grade with the stockpiled topsoil and readied for seed, sod, or other landscaping amenities. Essentially, the site is permanently stabilized.

The actual sequence of construction operations described here will vary depending on the site, type of development, contractor, and weather conditions. The construction sequencing should coordinate with the erosion and sediment control plan as to give a verbal blueprint for how the site should be constructed. There should also be flexibility in the sequence to allow for changes in weather or contractor preferences.

THE EROSION AND SEDIMENT CONTROL PLAN

A well-conceived plan for a project addresses the potential erosion and sediment problems long before the final construction plans begin. The overall E&S control plan begins at the early planning stages of the project. Such things as fitting development to the terrain, minimizing grading in sensitive areas (e.g., steep slopes and areas of highly erodible soil), and preserving existing vegetation all factor into the E&S control plan and must be considered at the earliest stages of development. The specific design and placement of structural control devices is done in the latter stages of project design after the buildings and infrastructure details have been worked out. This part of the E&S control plan is dynamic in that the E&S control measures change with the phasing and sequence of construction. The final design stage of the E&S control plan is a follow-through of the overall plan devised at the beginning of the project.

The E&S control plan sheets, included in the set of construction drawings, typically consist of plan sheets, detail sheets, and a narrative. Together, they describe and illustrate the procedures and measures that mitigate the erosion potential of the site and prevent off-site sediment damage. Many localities require an E&S control plan as part of the construction drawing set. The E&S control plan is just one part of the construction documents and, as such, is subject to review and approval by the specified public agencies. The length and complexity of the plan depends on the project size, constraints of the site, and the regulations in effect. Hence, a relatively small site in acreage may require extensive erosion and sediment control due to the soils, slopes, and environmentally sensitive areas within it, while a large open site with very flat uniform terrain may have minimal controls.

Development of an E&S control plan initially requires information on:

- Erodibility of the surface and immediate subsurface soils
- Extent and type of vegetation covering the site
- Hydrologic conditions such as depth of rainfall for the design storm and average intensity
- Topography—steepness of slopes, length of slopes, existing drainage pattern, and contributing off-site drainage
- Capacity of outfall channels and downstream structures

Most of this information is obtained from local government agencies and other regional public agencies in the form of maps and reports. Typically, most of this information has been used earlier in the planning and design of the project and is readily available.

The overall E&S control plan can be broken down into three categories, where each category addresses specific aspects of E&S control for the site. The three categories are planning, design, and installation and maintenance.

During the planning phase, certain issues need to be considered in the layout of the site. If these issues are adequately addressed, the selected measures in the later phases will be both cost effective and successful in eliminating off-site damage.

The issues considered early in the project are as follows:

- *Fitting the development to the terrain.* Design and site the building structures so that they are compatible with the topography. Optimize vertical and horizontal road alignments to minimize grading activity.
- *Identifying the on-site soils for their erodibility.* Soil maps are available for most areas in the United States from the Natural Resource Conservation Service (NRCS). Erodibility of soils depends on the slope lengths and gradients. Long, steep slopes will have more erosion potential. Hence, locating the soil series and its erodibility on a topographic map of the site identifies critical areas. The erodibility may be given in general terms (e.g., slight or moderate) or the erodibility of the soil may be identified by the K factor of the USLE; the local Soil Conservation Service office can supply the K factor values. Configure the site to minimize the disturbance of the highly erodible soils. Additionally, minimize disturbance of existing steep slopes. Denuded slopes exacerbate erosion potential regardless of the erodibility of the soils on the slopes.
- *Preserving existing vegetation.* A site visit will identify the areas of good stands of trees and vegetation. Preserving existing natural vegetation not only decreases erosion potential, but also enhances the land value and conserves energy. Site the buildings and structures to take advantage of the scenic value of trees and vegetation.

Unfortunately, marketing issues, land values, and environmental preservation quite often conflict with the priorities of the developer, public officials, and citizens. It may not always be economically feasible to develop the site in a manner that best fits the interests of all parties. The priority of the previously listed issues will vary from site to site. An alternative is to compensate the E&S controls through extra structural measures or more tightly controlled construction phasing. Consideration should be given to determine whether the cost for the extra measures is warranted. After the planning phase is complete and the planners have done everything reasonable to meet the developer's goals, comply with local ordinances, and address environmental issues, the next phase is to design the E&S control plans. These plans detail where, when, and what type of structural measures are to be installed and include any related computations supporting the design. Construction phasing is also shown on the plans.

The placement and sizing of structural measures require knowledge of construction techniques and construction sequencing. The engineer who is unfamiliar with construction techniques can develop a plan, but in all likelihood it will not be very effective. Ideally the engineer should coordinate the design of the sediment control plan with the developer's contractor to provide the most efficient set of plans possible and thereby reduce the cost to the owner/client.

Developing the Plan Sheets

To develop a set of E&S control drawings that are feasible and cost effective, the designer needs to address the specific issues previously discussed. Each site is unique, and the priority or sequence of the issues is not always the same. To begin, the engineer obtains copies of the plan sheets that show the location of the buildings, streets, and utilities with the existing and proposed grades. All other pertinent features should be included on the plan sheets (e.g., streams, lakes, and other environmentally sensitive areas, adjacent properties). These sheets will serve as their worksheets to develop the E&S control plan sheets. Depending on the project, the designer may need to add a smaller-scale composite view of the entire project to show the overall layout of multiple large-scale plan sheets.

The main objective of the erosion control plans is to clearly communicate the E&S control design to the approving public agencies and the contractor. This includes selecting the appropriate E&S control measures and their location on the site. Table 27.10 suggests the symbols used on plans and summarizes the protection afforded by the particular measure.

First, the engineer considers whether any specific phasing is necessary. Phasing may be necessary if one area of the site has to be graded before another to provide fill dirt for another portion of the site. A stream crossing may dictate which por-

TABLE 27.10 Summary of Symbols and Types of Selected Erosions and Sediment Control Measures

Title	Key	Symbol	A Perimeter Control	B Slope Protection	C Sediment Trapping	D Drainageway and Stream Protection	E Temporary Stabilization	F Permanent Stabilization
Temporary gravel construction entrance	CE		✔				✔	
Straw bale barrier	STB		✔		✔	✔		
Silt fence	SF		✔		✔	✔		
Storm drain inlet protection	IP				✔			
Temporary diversion dike	DD		✔	✔				
Temporary sediment trap	ST		✔		✔			
Temporary sediment basin	SB		✔		✔			
Temporary slope drain	TSD			✔			✔	
Paved flume	PF			✔				✔
Outlet protection	OP					✔		✔
Check dams	CD					✔	✔	
Level spreader	LS		✔			✔	✔	
Temporary seeding	TS						✔	
Permanent seeding	PS							✔
Sodding	SO					✔		✔
Mulching	MU						✔	
Tree preservation and protection	TP							✔
Dust control	DC						✔	

(*Source: Virginia Erosion and Sediment Control Handbook.* 1992)

tion of the site is worked on first due to access or permitting requirements. Phasing should also be considered during some projects that require the initial construction of model homes to promote marketing and sales within the development. The engineer needs to consider such issues at the outset and weigh their impact on the project's development.

After establishing the need for project phasing, the limits of clearing and grading that apply to the phasing are addressed. Typically, the limits of clearing and grading are the points where the proposed contours tie into the existing contours. If any intermediate land-disturbing activities are planned, the engineer may decide to show the clearing and grading limits separately for each activity. For example, if the entire site can be constructed (e.g., utilities, pavement, and building) within the prescribed maximum cleared area, only perimeter controls may be needed. If a site requires mass

General land conservation notes

1. All land conservation activities shall be performed in accordance with the latest Fairfax County checklist for erosion and sediment control, the public facilities manual, and the Virginia Erosion and Sediment Control Handbook.

2. No disturbed area will remain denuded for more than 14 calendar days unless otherwise authorized by the director or his agent.

3. All erosion and sediment control measures are to be placed prior to or as the first step in grading. First areas to be cleared are to be those required for the perimeter controls.

4. All storm and sanitary sewer lines not in streets are to be mulched and seeded within 5 days after backfill. No more than 500 feet are to be open at one time.

5. Electric power, telephone and gas supply trenches are to be compacted, seeded and mulched within 5 days after backfill.

6. All temporary earth berms, diversions and sediment control dams are to be mulched and seeded for temporary vegetative cover immediately after grading. Straw or hay mulch is required. The same applies to all soil stockpiles.

7. During construction, all storm sewer inlets will be protected by inlet protection devices, maintained and modified as required by construction progress.

8. Any disturbed area not covered by note #1 above and not paved, sodded or built upon by November 1, or disturbed after that date, is to be mulched with hay or straw mulch at the rate of two tons per acre and over-seeded immediately.

9. At the completion of construction projects and prior to the release of the bond, all temporary siltation and erosion controls shall be removed and all disturbed areas shall be stabilized.

10. No area shall be left denuded for a period longer than 14 days except for that portion of the site in which work will be continuous beyond 14 days. In the event such maximum period is exceeded and any such areas remain exposed without cover, the county will (in the event the developer or builder does not) install the necessary temporary or permanent vegetative stabilization measures to achieve adequate erosion and sediment control.

11. The cost of any such temporary measures taken by the county shall be borne by the developer and shall be a charge against the conservation deposit.

Project description

The purpose of this project is to provide adequate ingress and egress from the property, allowing it to be fully developed into a residential subdivision under the current zoning. The clearing and grading area required for this development is approximately 9.42 acres.

Existing site conditions

The site is primarily wooded with some open areas found near the existing Vernon drive cul-de-sac. The site is divided into two distinct drainage areas split by a ridgeline that runs northwest to southeast through the site. The southern side of the site drains by sheet flow into an existing adequate swale. This swale connects downstream to an unnamed tributary of Difficult Run, which drains through the Wolf Trap Green subdivision. The remainder of the site drains by sheet flow and shallow concentrated flow to an existing unnamed tributary of Difficult Run which crosses the northeast corner of the site. 100% of the onsite runoff enters these two swales. The majority of the onsite runoff (approximately 70%) flows to the northeastern most swale. These swales ultimately convey the on-site storm runoff to Difficult Run.

Soils

Soils were mapped by Fairfax County soil survey office February 10, 1982 with the following results: mixed alluvial land that is basically contained within the EQC line at the northeastern side of the property. Connection to an existing sanitary sewer and outfall of the storm sewer is proposed within the area of this soil. Meadowville silt loam at 3% slope, Manor silt loam at 6% in the rolling phase, and Glenelg silt loam at 4% in the rolling phase. The meadowville soil type is characterized as having wetness problems and therefore creating possible foundation problems. Adequate foundation drainage as well as inspection of foundation subgrades should be done on construction of these areas. Glenelg silt loam and Minor silt loan, however, are characterized as having both good subsurface drainage and foundation support but also a severe potential for erosion.

FIGURE 27.33 Erosion and sediment control narrative.

PHASE 1: (Initial clearing and grading)
Erosion and Sediment Control Measures

A. A construction entrance with a wash rack shall be installed) if water is not readily available, a water tank shall be the source of water). A small temporary silt trap will catch wash rack water.

B. Silt fences and tree protection shall be installed as shown in this plan.

C. Two sediment basins shall be installed as shown on the plan. See sediment basin calculations on sheet 16 and details on sheet 11. The sediment basins shall be inspected on a regular basis and restored to their original capacity when sediment has accumulated to the clean out elevation. (See sediment basin computations.)

D. A temporary diversion dike will be installed near the limit of grading as shown on the plan and directed towards the sediment basins.

Maintenance program

1. The site superintendent, or his/her representative, shall make visual inspection of all mechanical controls and newly stabilized areas (i.e. Seeded and mulched and/or sodded areas) on a daily basis; especially after a heavy rainfall event to insure that all controls are maintained and properly functioning. Any damaged controls shall be repaired prior to the end of the work day including re-seeding and mulching or re-sodding if necessary.

2. All sediment trapping devices shall be cleaned out at 50% trap capacity and the sediment shall be disposed of by spreading on the site or hauling away if not suitable for fill.

Drainage Area A:
The majority of the runoff contributing to this area is from the proposed Vernon Drive extension. A very small portion of the runoff comes from offsite as shown in the plan. Flows are picked up by structure 5. Flows are then conveyed to bed and banks on parcel "A" through the underground storm pipes.

Drainage Area B:
This area is comprised of portions of lots 3 through 8. Runoff is picked up at the low point in the cul-de-sac by structure 4. Flows are then conveyed to bed and banks on parcel "A" through the underground storm pipes.

Drainage Area C:
This area is comprised of portions of lots 8 and 9. Runoff is picked up by structure 6. Flows are then conveyed to bed and banks on parcel "A" through the underground storm pipes.

Drainage Area D:
This area is comprised of lots 9, 10 and 11. Runoff is picked up by structure 7. Flows are then conveyed to bed and banks on parcel "A" through the underground storm pipes.

Drainage Area E:
This area is comprised of portions of lots 15 and 16, and portions of offsite Kenmore Farms Lot "7." Runoff is picked up by structure 12. Flows are then conveyed to bed and banks on parcel "G" of adjacent Wolf Trap Green, Section Two by means of underground storm pipes and a sodded ditch.

Drainage Area F:
This area is comprised of lots 11 through 14. Runoff is picked up at the low point in the cul-de-sac by structure 11. Flows are then conveyed to bed and banks on parcel "G" of adjacent Wolf Trap Green, Section Two by means of underground storm pipes and a sodded ditch.

Drainage Area G:
This area is comprised of portions of lots 14 and 15, and offsite lots 4 and 7 of Kenmore Farms. Runoff is picked up at a low point by structure 13. Flows are then conveyed to bed and banks on parcel "G" of adjacent Wolf Trap Green, Section Two by means of the underground storm sewer pipes and a sodded ditch.

Drainage Area H:
This area is comprised of portions of lots 12 through 14, parcel "B," and offsite lot 4, Kenmore Farms and Route 7. This area also receives flows from drainage areas E, F and G through the underground storm pipes. Flows are conveyed by bed and banks on Parcel G of adjacent Wolf Trap Green, Section Two by means of a sodded ditch.

Figure 27.33 *(Continued)*

Drainage Area I:
This area is comprised of a portion of lot 9 and the existing Myra drive turn-around. Runoff is picked up at the low point of the Myra Drive turn-around by structure 8. Flows are then conveyed to bed and banks on parcel A through the underground storm pipes.

PHASE 2: (Final clearing and grading)

Erosion and Sediment Control Measures

A. After all sediment and erosion control measures have been installed in accordance with the phase I plan, and upon approval of the county inspector, the contractor shall clear only the areas needed for street and utility construction to minimize erosion. As soon as grading allows streets will be stabilized with base stone and the remainder of the site shall be cleared when necessary. Phase I diversion dikes and basins shall be left in place for as long as possible and gradually removed after street areas are stabilized.

B. Inlet protection shall be placed on storm inlets as soon as they are installed. Outlet protection shall be placed as soon as outlet structures are in place.

C. For additional information please see land conservation notes.

Maintenance Program

1 The site superintendent, or his/her representative, shall make visual inspection of all mechanical controls and newly stabilized area (i.e. Seeded and mulched and/or sodded areas) on a daily basis; especially after a heavy rainfall event to insure that all controls are maintained and properly functioning. Any damaged controls shall be repaired prior to re-sodding if necessary.

2 All sediment trapping devices shall be cleaned out at 50% trap capacity and the sediment shall be disposed of by spreading on the site or hauling away if not suitable for fill.

FIGURE 27.33 (*Continued*)

grading and borrow areas, intermittent controls will be necessary around the borrow areas as well as the immediate site area. Alternatively, the intermediate activities can be described or clarified in the narrative.

Clearing limits for trenching of utilities often extends beyond the width of the easement. The clearing limits for these activities depends on how deep the trenches are and whether the contractor will use shoring to stabilize the sidewalls. Sloping or benching the sidewalls of the trenches, which is an alternative to shoring, requires extending the limits of clearing and grading beyond where the proposed and existing contours meet. If the trench walls will be sloped, typically 1H:1V, the clearing limits will be a distance equal to the depth of the trench on either side of the centerline of the excavated trench. Note that extra room is necessary on one side of the trench for placing the excavated soil.

The selection and placement of E&S controls is related to the existing drainage pattern of the site as well as the intermediate drainage patterns during construction and land phasing. The engineer delineates the drainage divides for the site's existing and proposed conditions. The drainage divides will reveal off-site sources contributing surface runoff, areas draining to existing and proposed storm drain inlets, and areas draining to all outlet points that discharge concentrated runoff outside the denuded area. After establishing the existing and proposed drainage divides, the engineer quantifies the runoff for each drainage area. Depending on the jurisdiction and size of the drainage area(s), either rational or SCS hydrologic methods may be used to compute peak runoff. The engineer also needs to quantify the water discharged onto the site from swales, ditches, and pipes conveying water from off-site sources. On most projects, it is likely that the drainage areas and calculations of the runoff have been done during an earlier stage in the design process. The design and installation of structural E&S control measures may be considered a two-phase process, described next.

Phase 1. The initial clearing and grubbing operation denudes a large area. This is the most critical stage for control of erosion and sedimentation. Before denuding a large area, E&S controls are installed along the perimeter of the work area and at the outfall of the site. Since some sites are not located along streams, outfall means anyplace where concentrated water will be discharged from the site. Placing these initial controls along the perimeter allows the builder to begin clearing and grading operations with minimum obstructions. The construction operations should be able to continue with little interruption from relocating or construction of additional controls.

Along the perimeter on the upslope sides, berms are built to divert clean, off-site runoff away from denuded areas. Along the low areas, berms and trapping facilities are constructed to divert and detain the sediment-laden runoff. Silt fence or super silt fence is installed to filter sheet flow runoff before leaving the site. If the denuded area is large and the flow concentrated, major sediment basins may be needed to protect the outfall points. These sediment basins are kept in place until the proposed conveyance systems are constructed and the upstream contributing area is stabilized.

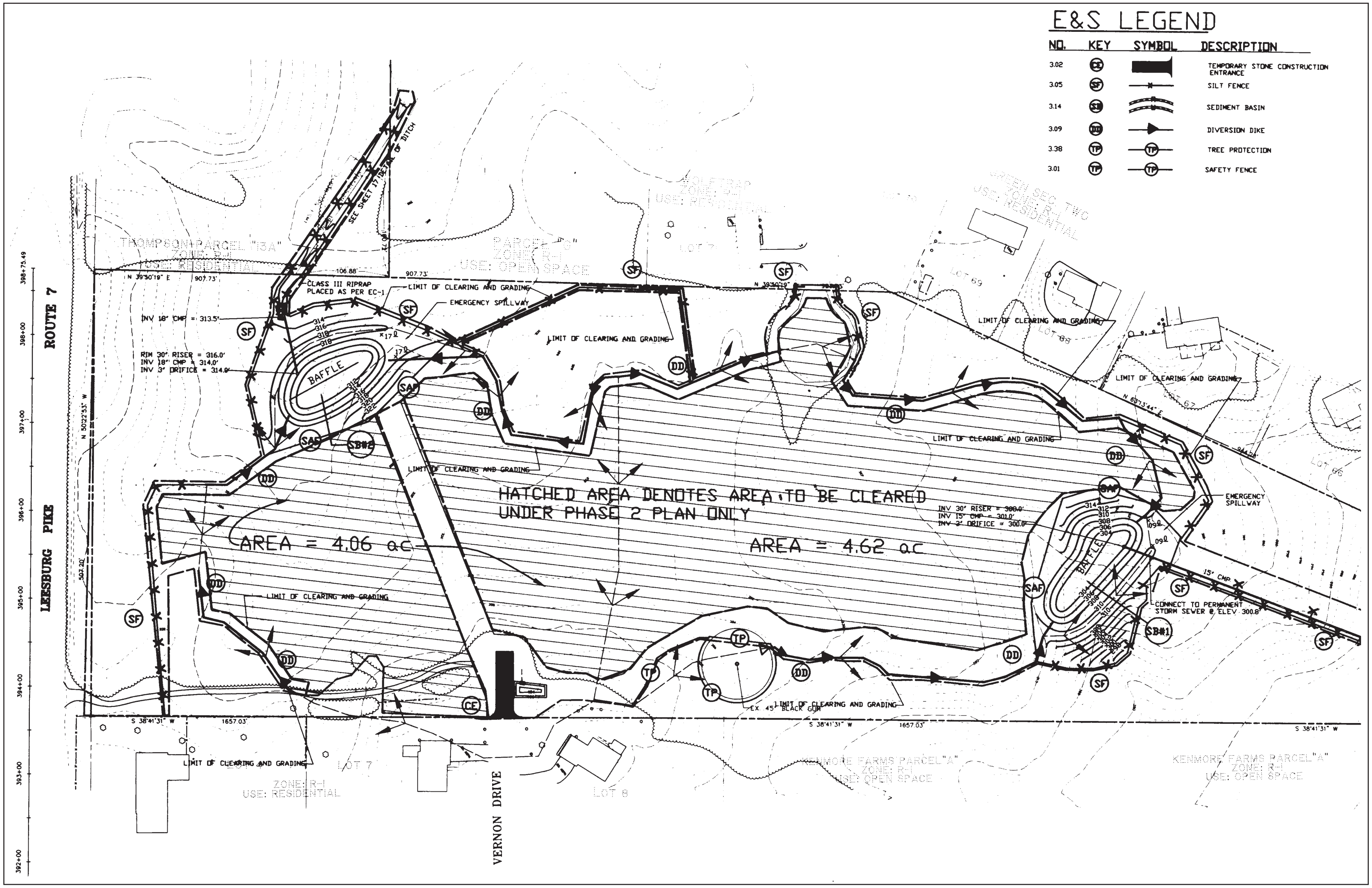


FIGURE 27.34 Phase I erosion and sediment control plan.

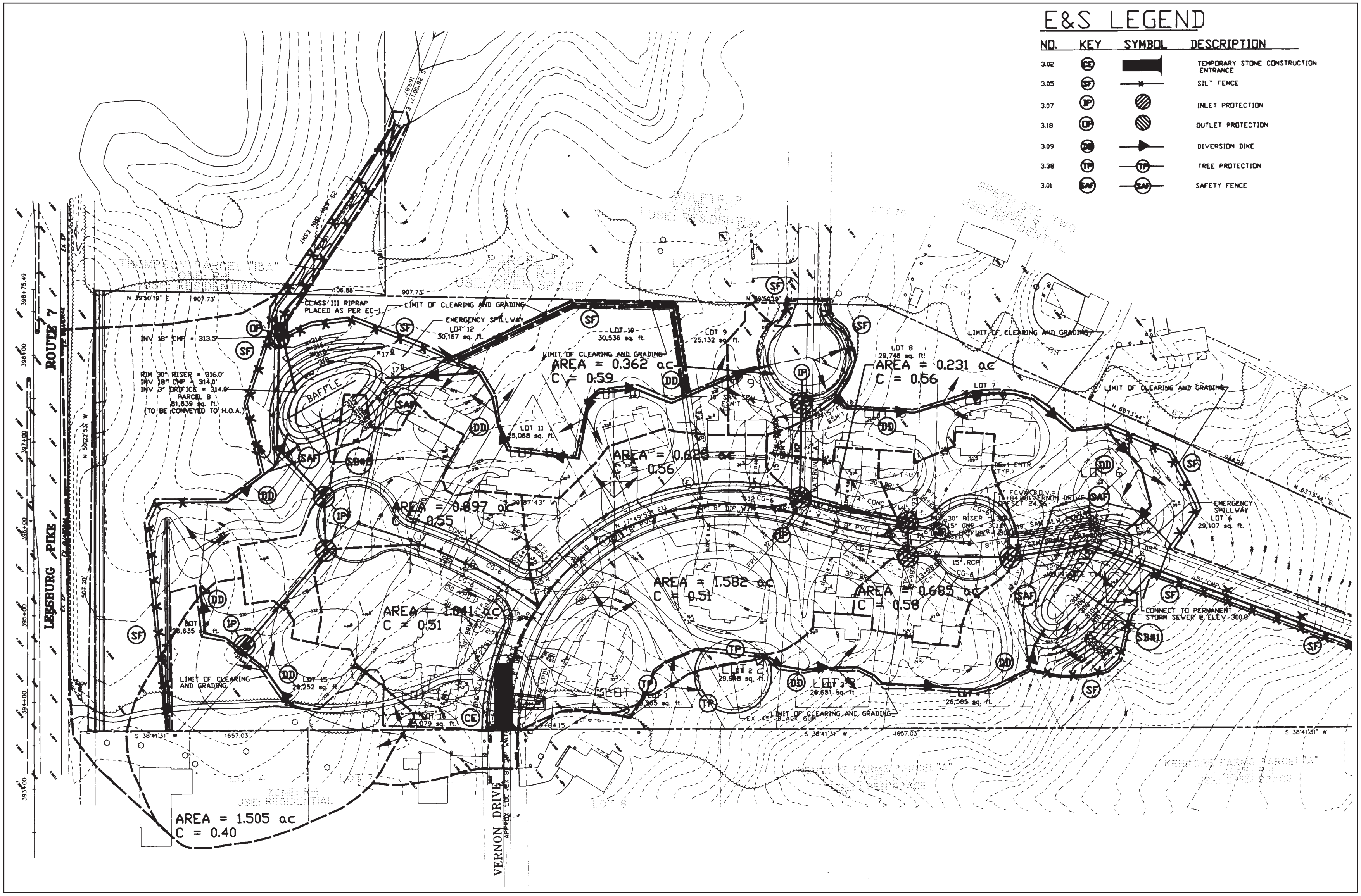


FIGURE 27.35 Phase II erosion and sediment control plan.

Phase II. As the construction operations progress, the drainage pattern evolves from the natural one (existing prior to construction) to the ultimate pattern, as shown on the construction plans. This evolution creates smaller drainage areas from the existing larger drainage areas. During the course of the evolution, modification to E&S controls may be necessary to reflect the changes in the drainage pattern. This includes eliminating any unnecessary controls and establishing new controls where appropriate.

As construction of the site progresses to the point where the grading matches the construction plans and the area is permanently stabilized, sediment traps and basins may no longer be functional and can be removed with the inspector's approval. As other areas are stabilized with vegetation and mulch, the E&S control devices are removed and the area is reworked and graded to match the construction plans. As always, the removal of any control devices is contingent on the approval of a site inspector who represents the engineer or local public agency.

The Narrative

The narrative to the E&S control plan is a list of notes that describe pertinent site features relating to erosion and sedimentation. The narrative conveys the engineer's design intent for the E&S control design to others reading the plan. The narrative describes the expected erosion and sedimentation problems, identifies the problem areas, explains any phasing of land-disturbing activities, clarifies any erosion and sediment control sequencing, and documents the types of measures to be used and the maintenance schedule as well as the inspection and provisions for repair of the measures.

The purpose of the narrative is to summarize the plan for the reviewer in the public agency, the site inspectors, and the contractor. In preparing the narrative, the engineer assumes the reviewing agency personnel are not familiar with the site and provides sufficient detail for their benefit. The narrative needs to be short and concise yet still supply the information needed.

Although the narrative may not be required in all jurisdictions that require E&S control plans, it is recommended that a narrative be included as part of the plan, especially for sites that require complex arrangements of erosion and sedimentation controls. The narrative explains the problem areas of the site, specifically explains the phasing, and clarifies any confusing situations shown on the plan view, which hopefully will help prevent future problems.

The narrative should include information regarding the following topics:

1. Project description: type of project, area that will be disturbed, number of units (residential) or square feet (single-parcel commercial/industrial sites).

2. Description of existing site conditions: topography, vegetation, streams, lakes, and drainage features.

3. Description of adjacent areas that might be affected by land-disturbing activities: streams, lakes, roads, and residential and commercial areas.

4. Description of soils: soil series and their erodibility.

5. Critical areas such as steep slopes, wetlands, and other environmentally sensitive areas.

6. Erosion and sediment control measures (e.g., berms, number of basins, and general location).

7. A description of phasing sequence and amount of area to be denuded when construction phasing is necessary.

8. Maintenance: A schedule for inspections, cleanout, and repair of the structures. Occasionally, the phrase "as needed" is used as an all-encompassing blanket phrase to describe when repairs and clean out should be performed, but the phrase should be avoided. Technically, the term is vague: "as needed" by whom? The public agency, contractor, engineer, and others will have different definitions for "as needed." Therefore, the description of inspections and repair should be explicitly specified (e.g., ". . . every two weeks," or ". . . after any rainstorm greater than 0.25 inches").

9. Permanent stabilization: Methods used to permanently stabilize the site (e.g., seed and sod).

10. Calculations and assumptions: Design of sediment basins for efficiency and other factors requires detailed calculations. Along with the calculations, the engineer will have to make assumptions when data is not available. The calculations should include a brief heading describing the calculation. Some jurisdictions require the calculations and assumptions to be included on the actual plan adjacent to the particular facility they describe rather than in the narrative.

An example of a narrative is shown in Figure 27.33 and the corresponding E&S control plan (Phase I) is shown in Figure 27.34. A Phase II type of E&S control plan is shown in Figure 27.35

SUMMARY

To summarize, the fundamental concepts common to erosion and sediment control plans are as follows:

1. Begin sediment control design at the earliest stages of development by limiting the area of clearing/disturbance, thereby reducing the amount of erosion and need for sediment control.

2. Clear only areas that will be worked on immediately. Mass site grading should be avoided.

3. Stabilize all disturbed areas as soon as construction is complete or when the areas will not be worked on for extended periods of time (e.g., more than two weeks).

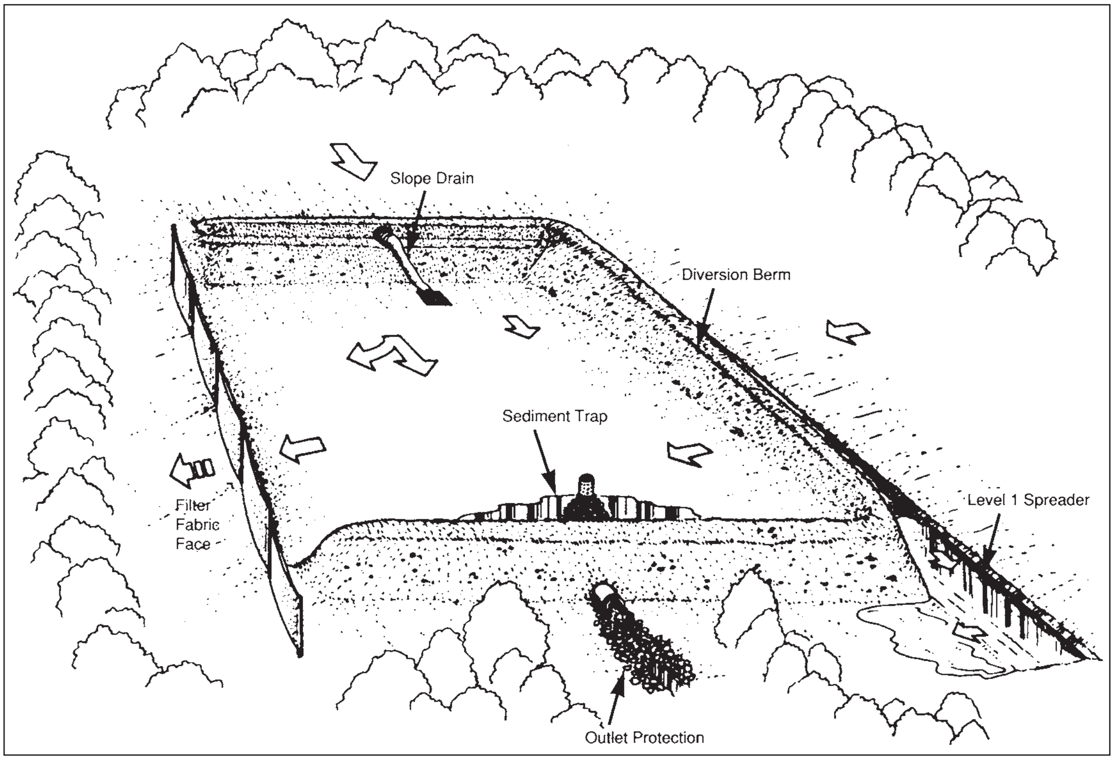


FIGURE 27.36 Schematic for erosion and sediment controls.

4. Direct non-sediment-laden water away from disturbed areas and divert sediment-laden water to trapping/filtering controls.

The erosion and sediment control plan is an integral part of the overall scheme of the development program and should not be created as an afterthought just because regulations require it (see Figure 27.36). Often, designers add E&S controls to the plans after the grading/development plan is nearly complete without any thought to the practicality of the controls.

Any E&S control measure called for in the plan should be able to be implemented in the field at the time of its need. It is easy to put symbols on paper for silt basins, silt fence, and berms, but the engineer has to ask whether they can be built as shown. Is the implementation accessible during construction so it can be maintained and can the device be easily removed once construction is complete? The engineer must think through the construction process with respect to the controls shown on the plan and make sure that a clear constructible set of plans is being presented that meets the developer's goals while allowing flexibility for the contractor. If need be, clarify ambiguous or controversial situations in the narrative.

Additionally, as a result of the NPDES permit program, construction sites are required to prepare a Storm Water Pollution Prevention Plan (SWPP) prior to commencement of any land-disturbing activities greater than 1 acre in size. The goal of the SWPP is to maximize the potential benefits of the pollution prevention and erosion and sediment control practices through the use of best management practices during the construction process. Since the primary focus of this program is on controlling pollutants in any stormwater discharge, incorporation of well-conceived and carefully implemented erosion and sediment control measures is more important than ever.

The descriptions of the specific structural measures have been limited here to those that are most frequently used in an erosion and sediment control plan. Other measures exist, and the reader is referred to local standards manuals for measures needed to accommodate the nuances for a specific locality or site condition.

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CHAPTER 28

CONSTRUCTION AND CONTRACT DOCUMENTS

Dan M. Pleasant, PE

INTRODUCTION

The land development process follows a logical sequence of steps from feasibility and site analysis through design and permitting and, finally, to construction. Each step results in an end product or deliverable that supports the next step in the land development process. Each step and resulting deliverable is addressed in detail in Chapters 2 through 34.

As illustrated in Figure 28.1, the land development process ultimately results in the construction of the project. It is important to recognize, even during the early planning and design steps, that after the construction is complete the project will need to be maintained and managed. This demands that the planning and design professionals give proper consideration and weight to minimizing the project impacts to the environmental, operational, and life cycle costs. This may include using low-impact development (LID) techniques, adhering to the U.S. Green Building Council's LEED criteria or other green building guidelines, or following other environmentally sound design strategies.

For a project to be successful, the design, including details, standards, quality, and performance criteria, must be fully and properly communicated to the construction contractor. This is done through the project construction and contract documents.

The composition of construction documents has evolved over time; however, the primary goal—communication of the project design and owner requirements to the builder or contractor—has remained constant. Going back to ancient times, this was typically accomplished through drawings supplemented with written words (or specifications). Today, drawings and specifications together with a legal agreement constitute what is typically referred to as the *construction documents* or the *contract documents* (see "Definitions" section).

It is important to understand that the content of the construction or contract documents, particularly as it relates to the contract terms and conditions, will differ depending on whether the project owner is a public-sector entity (local, state, or federal government) or a private-sector business or corporation. In general, public-sector clients have more specific requirements, regulations, and standards that must be incorporated into the contract or construction documents. This may include public bidding and procurement regulations and procedures, required design standards and specifications, and special documentation and reporting requirements. Private-sector clients, while having to adhere to the design and construction regulations of the permitting agencies and jurisdictions, generally have much more flexibility with regard to construction bidding and procurement.

DEFINITIONS

The Construction Specification Institute (CSI) is a national professional association of members who represent the design and construction industries. CSI is a recognized industry leader in developing standards and formats for construction specifications and project delivery. The definitions provided here are consistent with the *CSI Manual of Practice*.

Bidding/procurement requirements: Instruction and information to bidders of a construction project including advertisement or solicitation, bid forms, and other requirements of bidders

Contracting requirements: Legal documents and requirements addressing the contractual obligations of

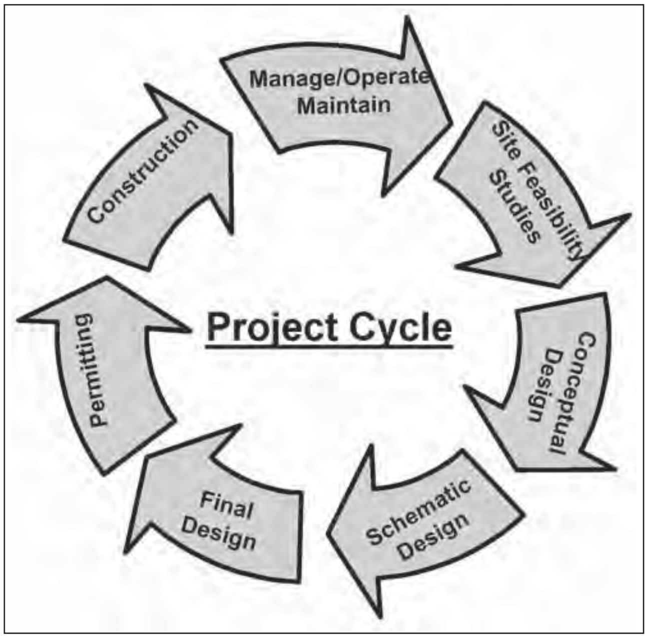

FIGURE 28.1 Project cycle. (Figure courtesy of Waller S. Poage III)

the bidder/contractor including contract form, bonding requirements, and general contract requirements

Specifications: A detailed written description of the qualities, requirements, materials, performance standards, and workmanship of a product, system, or equipment item to be used in the project construction

Contract drawings: Graphic representation of the project design providing location, dimensions and size, relationships, details, assembly, and textual information

Construction documents: Include all written and graphic documents (bidding/procurement requirements, contracting requirements, specifications, and contract drawings) prepared to communicate the project design and construction requirements

Contract documents: Include the legal form of agreement between the owner and contractor and the construction documents minus the bidding/procurement requirements

Project manual: Typically includes the written documents bound into a book format to include the bidding/procurement requirements, contracting requirements, and specifications

CONSTRUCTION DOCUMENTS: PACKAGING FOR PROJECT BIDDING AND CONSTRUCTION

The construction documents represents the complete package of written and graphic documents developed to communicate the project bidding/procurement requirements, design, technical specifications, construction requirements, and other owner requirements to the contractor (see Figure 28.2). These documents, minus the bidding/procurement requirements, together with the formal agreement or contract constitute the legal agreement—the contract documents—between an owner and a contractor for the construction of a project.

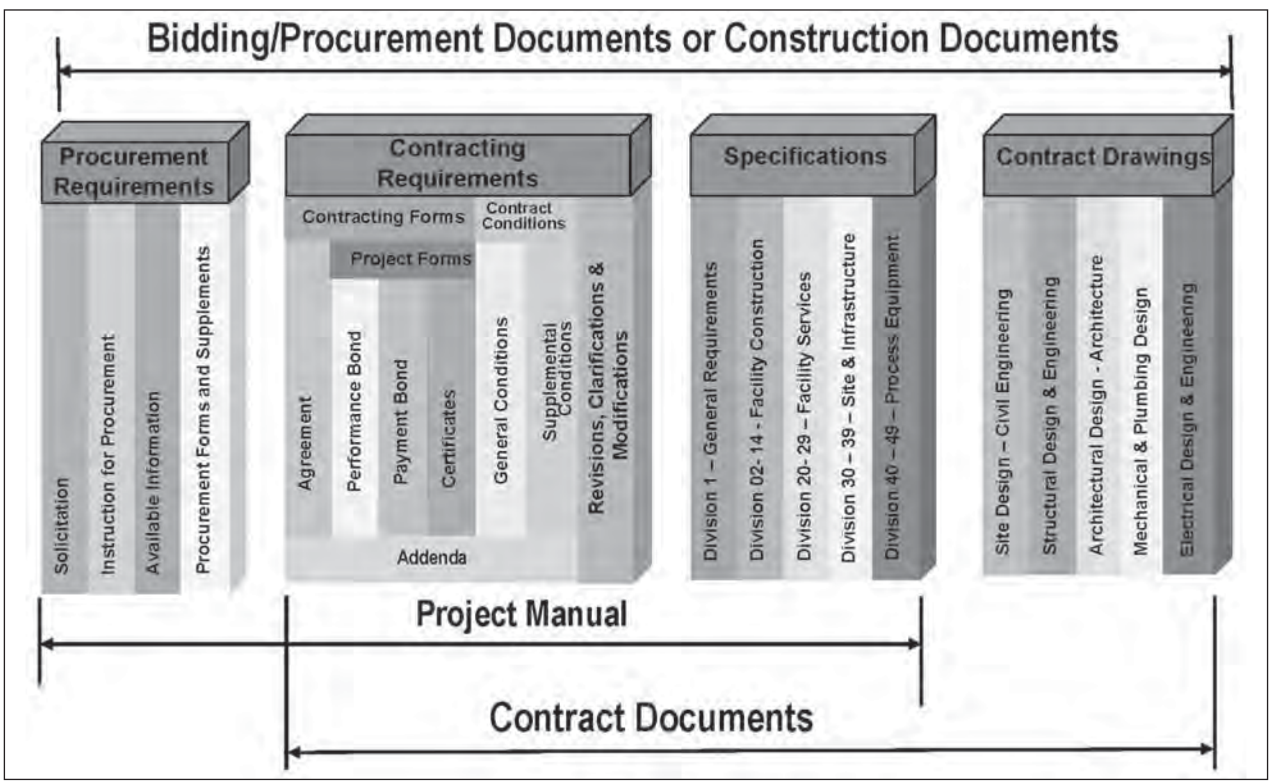

FIGURE 28.2 Family of construction documents. (Figure courtesy of Waller S. Poage III)

As the typical land development project progresses through the different design and permitting phases, the design professional is generally focused on preparing the project drawings and specifications. After final design is complete, the design professional often prepares and assembles the other documents that constitute the contract documents. Because these documents become a legal binding agreement, it is important to have the owner's legal counsel address the contract form and provide a review of the contract documents.

The construction documents for public-versus private-sector projects would generally be similar. However, the one difference is that public-sector projects generally have more special contracting requirements, certifications, and disclosure requirements. It is important on public-sector projects to include all applicable bidding/procurement requirements and contracting requirements from the public-entity client. If the project is for a local government entity, certain state and federal government requirements may be applicable if funds are being provided by state or federal agencies.

The different documents that constitute the construction documents are addressed in more detail in the following sections of this chapter.

BIDDING/PROCUREMENT REQUIREMENTS

The bidding/procurement requirements are the instructions and information to prospective bidders (contractors) for a project. In general, the bidding/procurement requirements allow an owner to solicit competitive bids for the project, with all bidders subject to the same contracting requirements and basing their estimates or proposals on the same information.

One important item addressed in the bidding/procurement requirements is whether the bidder/contractor would need to provide a performance and payment bond for the construction work. A bond is simply a warranty that provides protection to the owner in the event the contractor does not properly perform the work, does not pay subcontractors and suppliers, and/or defaults on the contract.

Other typical and important requirements for bidding/procurement include the type of bid and pricing requested (stipulated firm price, cost plus fee, or unit price), minimum bidder qualifications, location and time of bid submittal, time allowed for completion of project, damage provisions for failure to deliver project on schedule, and criteria for evaluation of the bids and award of the contract.

For public-sector projects, bids are typically received as sealed bids at a specified place and time. Bids are then publicly opened, read, and posted for public viewing. Any bidder that fails to comply with a bidding requirement is typically disqualified. The bid is typically awarded to the lowest responsible bidder.

For private-sector projects, the owner has significant flexibility in terms of soliciting and awarding a construction contract. In general, the owner is not required to obtain competitive bids and may choose to solicit bids from one or a selected few contractors. The owner then may negotiate a contract with the selected contractor deemed to be the owner's best option.

CONTRACTING REQUIREMENTS

The contracting requirements provide the form of agreement, the form for bonds (if required), and other terms and conditions (often referred to as general and supplemental conditions) related to the contract. As previously addressed in this chapter, the actual agreement or contract is only one document of the set of documents that constitute the contract documents. The actual agreement, or contract form, serves to legally obligate the signing parties, addresses certain contractual obligations, and enumerates the other documents (specifications, drawings, project manual, etc.) that constitute the full set of contract documents.

Standard construction agreements and contract forms are published and available from professional organizations and agencies. These are widely accepted and used for public- and private-sector construction projects. Standard form agreements are addressed in more detail in this chapter. Often public- and private-sector owners have their own custom contract form or, at a minimum, standard terms and conditions that are incorporated into a standard agreement form.

SPECIFICATIONS

The specifications provide a written description of the project requirements, construction materials, and the quality and performance standards for the products, systems, and equipment to be incorporated into the project. Specifications complement the drawings by providing an opportunity to communicate information to the builder/contractor that cannot be fully provided through the drawings.

The specifications are typically organized under general requirements and technical specifications. The general requirements address requirements that apply broadly to the entire project. This includes project administration, quality control, temporary facilities, payment procedures, and project closeout requirements.

The technical specification sections are organized by major work type (site preparation, utilities, grading, etc.) and define in detail the requirements for the products, equipment, materials, and workmanship. Technical specifications are written in four ways:

1. Descriptive specifications provide a very detailed description of the properties, workmanship, and installation requirements of a product, material, or equipment item.

2. Performance specifications provide a description of the required end product or results. The specifications set performance criteria and allow the contractor the flexibility to choose materials, systems, and equipment to meet the specified performance requirements.

Section 01352—LEED MR Requirements
Part 1. General LEED Requirements
1.1 Summary
A. Section includes general requirements and procedures for compliance with certain USGBC LEED MR credits needed for Project to obtain LEED Silver certification based on LEED-NC, Version 2.2.
1.2 Submittals
A. LEED Action Plans: Provide preliminary submittals within 14 days of date established for the Notice to Proceed indicating how the following requirements will be met:
1. Credit MR 2.1 and Credit MR 2.2: Waste management plan complying with Division 1 Section "Construction Waste Management."
2. Credit MR 4.1 and Credit MR 4.2: List of proposed materials with recycled content. Indicate cost, post-consumer recycled content, and pre-consumer recycled content for each product having recycled content.
3. Credit MR 5.1 and 5.2: List of proposed regionally manufactured materials and regionally extracted, harvested, or recovered materials.
a. Identify each regionally manufactured material, its source, and cost.
b. Identify each regionally extracted, harvested, or recovered material, its source, and cost.
B. LEED Progress Report: Concurrent with each Application for Payment, submit reports comparing actual construction and purchasing activities with LEED action plans for the following:
1. Credit MR 2.1 and Credit MR 2.2: Waste reduction progress reports complying with Division 1 Section "Construction Waste Management."
2. Credit MR 4.1 and Credit 4.2: Recycled content.
3. Credit MR 5.1 and 5.2: Regionally manufactured materials and regionally extracted, harvested, or recovered materials.
C. LEED Documentation Submittals:
1. Credit MR 2.1 and Credit MR 2.2: Comply with Division 1 Section "Construction Waste Management."
2. Credit MR 4.1 and Credit 4.2: Product data and certification letter indicating percentages by weight of post-consumer and pre-consumer recycled content for products having recycled content. Include statement indicating costs for each product having recycled content.
3. Credit MR 5.1 and 5.2: Product Data indicating location of material manufacturer for regionally manufactured materials.
a. Include statement indicating cost and distance from manufacturer to Project for each regionally manufactured material.
b. Include statement indicating cost and distance from point of extraction, harvest, or recovery to Project for each raw material used in regionally manufactured materials.

Part 2—Products
2.1 Recycled Content of Materials
A. Credit MR 4.1 and Credit 4.2: Provide building materials with recycled content such that post-consumer recycled content plus one-half of pre-consumer recycled content constitutes a minimum of 20 percent of cost of materials used for Project.
2.2 Regional Materials
A. Credit MR 5.1: Provide 20 percent of building materials (by cost) that are regionally manufactured materials.
B. Credit MR 5.2: Of the regionally manufactured materials required by Paragraph "Credit MR 5.1" above, provide at least 50 percent (by cost) that are regionally extracted, harvested, or recovered materials.

Part 3—Execution
3.1 Construction Waste Management
A. Credit MR 2.1 and 2.2: Comply with Division 1 Section "Construction Waste Management."

FIGURE 28.3 Sample specification—LEED MR requirements.

3. Reference standard specifications use standard specifications developed by recognized trades and professional and government organizations. These standards are simply incorporated into the technical specifications by reference.

4. Proprietary specifications are very specific and provide the contractor limited or no flexibility to choose among varying options. Proprietary specifications provide the supplier or manufacturer's name, product name, and specific characteristics. In general, proprietary specifications are not allowed in public-sector work, as it limits open and fair competition.

With the emergence of the importance of energy conservation and sustainability in the design and construction industry, it is critical to incorporate into the technical specifications the desired environmental performance requirements and criteria of the products and materials to be used in construction. This starts in the early stages of the design process when the design professional and owner make decisions on the project goals and strategies relative to energy efficiency, sustainability, and environmental performance. These goals and strategies are carried forward through the design process and development of the final construction documents, including the technical specifications. These environmental performance requirements become even more important if the project is seeking a certain certification level for sustainability as provided through USGBC's Leadership in Energy and Environmental Design (LEED®) rating system.

Projects seeking LEED certification require the design professional to carefully research and specify—in the contract documents—products that meet the LEED rating system credit requirements targeted as part of the overall project LEED strategy. It is also important that the specifications address the requirements of the contractor to provide certain plans and submittals to track and confirm compliance with the LEED requirements for the project. This may include LEED action plans addressing how the LEED requirements will be met (e.g., construction waste management plan, salvage/refurbish plan, regional material/product purchase plan, recycle/reuse material content plan); LEED documentation on specific construction products and plans (product data and confirmation of action plan compliance); and LEED progress reports during construction tracking actual LEED-related purchases and activities against action plans.

Beyond the sustainable sites credits and the water efficiency credits that are typically addressed by the land development consultant, it is important to note that site elements—pipes, inlets, manholes, other structures, sidewalk, and paving—can all contribute to meeting several credits within the Materials and Resources category of LEED. Particularly the Recycled Content and Local/Regional Materials credits (four points total) are based on achieving a certain percentage of the overall project cost including the site work (5 to 20 percent depending on the credit sought) through use of recycled and locally available materials. The example specification provided in Figure 28.3 addresses the submittal requirements of the contractor as related to LEED credits for MR2.1 and MR2.2—Construction Waste Management, MR4.1 and MR4.2—Recycled Content, and MR5.1 and MR5.2—Local/Regional Materials.

CONTRACT DRAWINGS

The drawings for a project go through various stages of development from conceptual to final, as noted in earlier chapters. The drawings at each stage of development also serve a purpose in the project development, permitting, approval, bidding, and construction processes. Typical drawings submitted for public agency approval are advanced design drawings, noted as not for construction, that are sealed and signed by the design professional (engineer, architect, or landscape architect) in responsible charge as required by the state professional licensing board regulations.

After public agency review comments are addressed and incorporated into the drawings, the drawings are considered final and are often referred to as the *construction drawings*. The construction drawings are used for bidding and for construction. When the construction contract is signed, the drawings become part of the contract documents and are often referred to as the *contract drawings*.

PREPARING CONTRACT DOCUMENTS AND SPECIFICATIONS

The preparation of the various documents that constitute the full family of construction documents (see Figure 28.2) is critically important to the success of a project. It is important because these documents will ultimately be used to communicate the project design and requirements to the builder/contractor and will become the legal binding agreement or contract between the owner and the builder/contractor.

Much has been written about and there are many references and books devoted to preparation of construction and contract documents. The information in this section provides an overview on the preparation of contract documents and specifications for construction projects, and highlights particular issues and items that are important in typical land development projects.

Bidding/Procurement and Contracting Requirements

The bidding/procurement requirements generally consist of an advertisement or solicitation for bid, instructions to the bidder, and the actual bid form for the project. The contracting requirements generally consist of the contract or agreement form and general conditions related to the contract including bonding requirements if applicable.

One option for development of bidding/procurement and contracting documents is to use standard documents that have been developed by recognized agencies and professional organizations. Such agencies include the American Institute of Architects (AIA) and the Engineers Joint Contract Documents Committee (EJCDC), which is comprised of the National Society of Professional Engineers, the American Consulting Engineers Council, and the American Society of Civil Engineers. When using these standard documents, it is important to understand that they have been developed as a family of documents with consistent language and format, common definitions, and cross references. Therefore, when using standard documents, select the most appropriate standard for the project and use this family of documents throughout the contract documents.

Important items and issues in preparation of bidding/procurement and contracting requirements documents for land development projects include the following:

- Determine the bidding requirements of the owner: if the project is in the public sector, the owner will have specific bidding requirements for sealed competitive bids; if the project is in the private sector, determine whether the owner will seek competitive bids, seek bids from a selected list of contractors, or negotiate with a preferred contractor.
- Determine if the owner requires the contractor to provide a performance and payment bond for the project.
- Determine if the owner has a standard contract form and contracting requirements.

- Determine the method for pricing/bidding the work. For land development work the pricing and bids are typically based on a stipulated firm price bid for the project or some portion of the project, or on unit price bids with corresponding estimated quantities resulting in a total bid for the project, or on some combination of stipulated and unit price bids. The bid form would be prepared according to the method of bidding and payment.

- Determine with the owner the contract time to be allowed for construction and whether a penalty (liquidated damages) would be assessed for noncompliance.

Specifications

Generally, when writing specifications for a land development project, one would start with an existing standard specification. The standard specification may be a standard developed by the professional design firm based on years of project experience, a standard specification provided and required by a public agency, or a standard specification developed by a recognized organization and commercially available for use. Such commercially available standards include AIA Masterspec® and the Unified Facilities Guide Specification (UFGS) used by federal military agencies.

There are also industry standards for the organization of specifications. While not typically used in stand-alone land development projects, these standard organization formats are typical for more comprehensive construction projects that may include the elements of site and land development. The most widely accepted and used specification organization standard is the CSI MasterFormat. MasterFormat provides a master list of specification topics by work results or construction practice. The specifications group includes Divisions 1 through 49 (some reserved for future use) with Division 1 being General Requirements. The Site and Infrastructure Subgroup applies mostly to land development projects and includes:

Division 31	Earthwork
Division 32	Exterior Improvements
Division 33	Utilities
Division 34	Transportation
Division 35	Waterway and Marine
Division 30, 36–39	(Reserved for Future Expansion)

Important items in the preparation of specifications for land development projects include the following:

- Determine whether the owner has standard specifications to be used for the project. If the land development work is part of a larger project, consult with the design team leader (may be the project architect) on specification standards and preferred organization.

- Address the sustainability and environmental design requirements of the project. This may include certain performance criteria required to obtain the desired level of certification as a LEED project.

- Make sure specifications are consistent with and complementary to the information shown on the drawings, but do not repeat or duplicate this information.

- Avoid language that defines work of specific subcontractors or trades. The contract documents, of which the specifications are one element, typically encompass the entire project and obligate the contractor for the entire project.

- Where reasonable, specify by referencing to an established and recognized industry standard. Organizations that develop and support such standards include American Society of Testing and Materials (ASTM), American National Standards Institute (ANSI), American Water Works Association (AWWA), American Concrete Institute (ACI), National Fire Protection Association (NFPA), International Code Council (ICC), and Association of State Highway and Transportation Officials (AASHTO). Also, many state transportation departments have standard specifications and construction details widely referenced and used in the construction industry in their respective states.

- Because specifications have legal consequences prepare them with care. Specifications should be coordinated with the drawings and contain only that information applicable to the project.

- When writing specifications, remember the goal is to clearly and concisely *communicate* the design and construction requirements to the contractor. Therefore, use simple sentence structure and be clear, direct, concise, and accurate.

Drawings

As previously noted, drawings are developed in stages and typically serve a specific purpose at each stage in the project development process. Ultimately the drawings are completed and used as part of the project contract documents for construction.

Drawings are generally developed and organized to certain standards. These standards may be developed by the professional design firm, a public agency, or recognized agencies including CSI and AIA.

Also, commercially available computer software allows development of "intelligent" drawings, thereby allowing development of material and product schedules, cross referencing to specifications, and three-dimensional conflict check and resolution.

When initiating a land development project, it is recommended to develop a comprehensive list of drawings that are anticipated for the owner's approval process, permitting, bidding, and construction. For each drawing, the information and graphics anticipated should also be documented. This list should be updated as the project progresses through the various stages from conceptual to final design.

Important items in the preparation of construction drawings for land development projects include the following:

- Determine whether the owner has standards for drawing preparation and organization. If the land development work is part of a larger project, consult with the design team leader (may be the project architect) on drawing standards and preferred organization.
- Make drawings consistent with and complementary to the information in the specifications, but do not repeat or duplicate this information.
- Avoid notes and details on drawings that define work of specific subcontractors or trades. The contract documents, of which the drawings are one element, typically encompass the entire project and obligate the contractor for the entire project.

CHANGES IN THE DESIGN AND CONSTRUCTION INDUSTRY AND THE IMPACT ON CONSTRUCTION AND CONTRACT DOCUMENTS

The design and construction industry is experiencing significant changes in how projects are planned, designed, constructed, operated and managed, and financed. This, in turn, has caused changes in how construction and contract documents are developed.

Sustainable Design

The increased emphasis on sustainable and environmentally sound design, including project owners' needs and desires to obtain LEED certification for their projects, has certainly caused changes in the content of construction and contract documents. For instance, the design professional's contract with the owner may include a requirement that the project be designed to obtain a given LEED certification level, and the contract with the builder/contractor may likewise have such requirements. The planning and design of the site elements of a project are important in meeting sustainability goals and gaining LEED certification. The civil engineer and landscape architect professionals, as part of a project design team, play an important role in developing the sustainability/LEED strategy for a project in the feasibility and conceptual design phases and in the execution of this strategy through the schematic and final design phases, including the construction documents. As an example, the specifications, as part of the construction documents for a project, would address the use of recycled, salvaged, and locally available materials; the selection of materials, systems, and products based on sustainability criteria; the selection of equipment based on energy efficiency criteria; and, in some cases, selection of major design elements of a project based on a complete life cycle cost analysis. It is imperative to include this information in the contract documents in order to accurately convey the owner's requirements, project goals, and the contractor's obligation or responsibilities in terms of achieving those criteria.

In order to facilitate the incorporation of sustainable or green building practices into the standard contract documents used in the industry, most form-based specification and bidding products commonly utilized are being modified to respond to the design and construction industry needs. One example is CSI's efforts to develop a database for tracking and reporting information on the sustainable attributes of building and construction materials and components. This CSI database, Green Format: A Reporting Guide for Sustainable Criteria of Products, provides design professionals with a tool to evaluate, select, and specify products to meet the sustainability goals of a project.

Alternative Project Delivery Methods

The use of alternative project delivery methods, particularly in the public sector, has significantly increased. In traditional delivery, design professionals are under contract with the owner, the project is bid, and the owner subsequently enters into a contract with a builder/contractor for the project construction. This is often referred to as the *design-bid-build* delivery method. The following project delivery methods for construction projects are being used more and more by private- and public-sector owners:

Design-build: Owner contracts with a team that includes the design professionals and contractor for the project. Contractor is typically the lead for the team.

Value-based award: Owner hires design professionals to prepare appropriate project construction documents. Bids are solicited from contractors (sometimes from a list of pre-qualified contractors) with requirements for price proposal and technical proposal. Award of contract is based on weighted evaluation of technical qualifications and price.

Design-build-finance: Owner contracts with a team that includes the design professionals, contractor, and financial institution. The team is under contract to deliver the project, including long-term project financing.

There are other hybrid construction delivery methods, but in general all result in the integration of the design and construction. These alternative delivery methods have given rise to the need for and development of new standard contract documents for the design professionals and the contractors. The Design-Build Institute of America (DBIA) was founded in 1993 to advocate and advance a single source (designer and contractor as a team) project delivery for construction projects. The DBIA has a family of standard contract documents for use on design-build projects. Also, the AIA, EJCDC, and Associated General Contractors of America (AGC) have modified and added to their family of standard contract documents to address design-build delivery.

Digital Documents

Use of digital documents, including submissions to public agency for review and permitting, is becoming more acceptable and prevalent. Also, the design and construction industry is moving toward exchanging contract document information in digital form. This includes transmitting construction documents (plans and specifications) to bidders for bidding and for construction. The state professional licensing boards that govern design professionals are amending their rules and regulations to facilitate use of digital documents.

REFERENCES

The Construction Specifications Institute (CSI). 2005. *The Project Resource Manual–CSI Manual of Practice,* 5th ed. New York: McGraw-Hill.

U.S. Green Building Council (USGBC). 2005. *LEED-NC for New Construction: Reference Guide Version 2.2,* 1st ed. Washington, DC: USGBC.

CHAPTER 29

CONSTRUCTION COST ESTIMATING

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INTRODUCTION

Development projects often begin with the developer or landowner approaching the land development team with a piece of property, and possibly a development program or intended use. The following economic or cost questions are likely to arise almost immediately and demand more precise answers as the project advances:

- Is the expense and effort involved worth the return, that is, is the site/project profitable?
- Can I complete the development in a reasonable amount of time?
- How much risk and potentially hidden cost does the development have?
- Is the project a good short-term investment? Long-term?
- Will people buy/rent/lease the product in a predictable period of time?
- Is adequate financing available to cover design and construction?

Construction cost estimates directly respond to some of these questions and facilitate finding the right answers to the others. Land development engineers are commonly requested to prepare cost estimates as part of the land development design process. The estimate's intended use largely determines the level of detail and the information required. In turn, the level of detail determines the time and, hence, the cost of preparing the estimate.

This chapter defines the possible purposes of estimates and identifies estimate types and their limitations. It is always important to state the assumptions that were made in the process of preparing the estimate. When preparing estimates with more detail, the importance of including all elements cannot be overstated. Therefore, we have provided a checklist of elements that should be included in the detailed estimate. Methods of estimating are identified, as well as sources of obtaining current information on construction costs.

Frequently the land development engineer is asked to compare the economic costs and benefits of several alternatives. For this reason, basic engineering economic theory and typical example problems are included.

PURPOSE OF COST ESTIMATES

Although cost estimates are prepared for both private- and public-sector projects, cost estimates for private land developers differ from those for public-sector clients in a very basic sense: construction cost estimates prepared for public projects, also called *capital projects,* are used to determine the economic benefit of the project based on public need, whereas cost estimates prepared for land development projects are used first by the entrepreneur to determine whether a project is economically feasible. The economic feasibility analysis combines the market analysis and the marketability study (performed by the developer/owner or qualified consultant) with development and construction costs garnered from feasibility analysis or preliminary design, debt structure, and the required rate of return, then tests the outcome in order to arrive at a go/no-go decision. For a small to midsize local or regional developer/builder, the decision is frequently based on the conjectures for the marketplace, the cost estimates provided by the consultants, and previous success with particular project types. In all development projects, location, timing, and cost control are the critical elements that must be evaluated carefully and consistently throughout the process in order to deliver a financially successful project.

Later, if the decision is made to proceed with development, a further refined cost estimate can be used to establish price points or selling prices of the product(s).

Public Project Cost Estimates

On a public project, three types of estimates are performed:

1. Preliminary cost estimates
2. Detailed cost estimates
3. Engineer's estimate or bid estimates

It is important for the land development engineer to understand the process by which a cost estimate for a public facility is prepared, since a publicly funded project is frequently an integral part of the overall land development venture.

The preliminary cost estimate for public projects is prepared prior to the development of detailed engineering plans and is used to solicit funding, generally from an annual capital improvement program, grants, or a voter referendum or bond issue. It is prepared with only a basic understanding of the general scope and extent of the project. Additional considerations are included, if known, such as special structures that are required; additional studies that may be warranted such as soil, wetland, or floodplain studies; land acquisition costs; and access considerations. The costs can be approximated using nationally published reference manuals (e.g., *RS Means*) or by using the local governing agency pricing guidelines. Often, costs from recently constructed projects of similar design are used as a source of cost data for such considerations. The accuracy of the preliminary cost estimate hinges upon the availability of accurate existing information and timely decisions regarding the details of the new development program. Generally, a significant contingency is included—as much as 30 percent—and frequently the cost of inflation is included since it may be several years before the project is actually constructed.

The detailed cost estimate is performed after the project is funded and designed. It is based on actual quantities estimated from the design plans. It is very similar to the detailed cost estimate for private projects, which is discussed in more detail later in this chapter. The detailed cost estimate should have an accuracy range of 10 to 15 percent.

The engineer's estimate or bid estimate is prepared as the project is awarded for construction. This estimate is very detailed and it should be as accurate as possible, within ± 5 percent of the actual cost. It should be based on a thorough review of the plans and specifications, the solicitation of prices from suppliers and specialty contractors, and the most recent cost of construction of the specific elements of the plan.

Private Project Cost Estimates

For private land development projects the types of estimates are:

- Feasibility cost estimates
- Preliminary cost estimates
- Construction cost estimates

The feasibility estimate is used by the developer in making a go/no-go decision. The preliminary cost estimate is performed after a plan has evolved but before the preparation of actual construction drawings. It is used by the developer to secure funding and to assist in developing alternatives before a final decision on product details. The construction cost estimate is prepared to finalize loan commitment and to compare bids from contractors. Each of these types of estimates is defined further in the next section of this chapter.

In summary, while there are some similarities between public and private project cost estimates, the uses to which these are applied vary. The purpose of the cost estimate for a public facility is to justify and prioritize the project components as well as determine the economic benefit or need as weighed against the cost to the public. The private land development cost estimate provides the developer with the all-important part of the development process: the cost to construct and, consequently, the amount that must be charged to recover these costs and still achieve the desired profit.

TYPES OF ESTIMATES

As stated previously, there are three basic types of estimates used in the private land development process:

- Feasibility cost estimates
- Preliminary cost estimates
- Construction cost estimates

Although there may be refinements or variations, these three constitute the main types of estimates. Generally, as a project progresses from the conceptual stage through design to construction, these estimates come into play to enable basic decisions for the project to be made. The primary difference between the three estimates is the level of detail on which the estimate is based.

Feasibility Estimates

Land development engineers are frequently requested by the client to assist in determining the initial feasibility of a project. In this process the general procedure is to review such elements as availability of services (utility services and their easements, public services, schools), the potential yield in terms of number of units or square footage of commercial or office space, potential environmental impacts, and a host of other elements (boundary and topographical surveys, soil tests and bearing capacity, need for retaining walls and special structures), all of which can impact the developer's bottom line (profit).

Many of these elements involve substantial expenditures, both in terms of fixed and capital costs. If the project is constructed at a time of high interest rates or when loaned capital is scarce, a well-prepared, all-inclusive cost estimate for the planned project is essential. It can ensure that the project is worthwhile or it can result in a decision to abandon the project before the incurring of any additional cost, including the development of detailed plans. Investment decisions by both the developer and the lender rely heavily on these estimates.

As technology changes, the consideration of alternate ways of performing some of the basic construction processes can be important. Cost estimates of each alternative can influence the final mix of technologies employed in a project. While the engineering portion of a feasibility study can determine whether the project can be performed technically, the economic or cost feasibility portion of the study determines whether it makes sense for the project to proceed financially.

It is common knowledge that many projects, which in the final analysis have lost monetarily, have been the result of decisions based on incomplete studies, obsolete information, or optimistic rather than conservative assumptions. A good rule to follow when estimating costs is to err on the side of conservatism.

Many times cost feasibility studies can be used to identify a better economical use of the parcel of land. For example, in evaluating the different lot sizes that can be placed on a parcel of land, one may attempt to maximize development lot yield by minimizing lot size. However, a cost feasibility estimate can provide information to establish the true cost of the individual lots. The result could determine that the most profitable mix might not be the one that results in the most units.

The feasibility estimate is used for exactly the stated purpose, that is, to determine the economic feasibility of any given item. That item can be the entire project or, on a smaller scale, a variation of a particular roadway alignment, bike path, or water main extension. Feasibility estimates can be separated into two types: (1) rough, or ballpark, estimates and (2) detailed feasibility estimates.

Rough, or Ballpark, Estimates. Many times during the course of designing a land development project, an engineer is asked to give an informal estimate to determine whether a particular item under discussion should be pursued or given further study and design consideration. These informal estimates are called "off-the-cuff" or "seat-of-the-pants" estimates. Unfortunately, the terms can imply humor and that these estimates need not be accurate and, hence, can be done by anyone. In truth, only seasoned engineers familiar with land development applications should give ballpark estimates, as only years of varied experience can allow them to ascertain what should be included in such an estimate. In addition, only with experience can one look at the final answer and know whether it makes sense. It may be better if the land development engineer provides the quantities and allows the owner/developer to provide the unit cost numbers, unless the engineer has some current costing data on which to render the opinion or the engineer contacts local contractors for their input.

In any case, it is important that the engineer document, in a memorandum, the assumptions and methodology. That memorandum can be given to the owner/developer if appropriate or requested and should be placed in the project files as a permanent record.

These types of estimates are also called *order-of-magnitude* estimates. Generally, they have a low level of accuracy and can vary by as much as 25 to 50 percent. While accuracy is sacrificed in these types of estimates, they can be useful for evaluating a large number of alternatives in a short period of time. One must always document assumptions and be aware of the inherent limitations of this process.

This rough estimating procedure presumes an upper-end average cost for the significant items of the project. One might assume a certain dollar cost per linear foot for installation of storm sewer pipe, even though the cost would actually vary according to pipe size and depth. If, however, there is only a small amount of storm sewer on the project and this cost, relative to other items in the project, is insignificant, then it might not be included in the ballpark estimate. Items such as this are lumped together in the ± 50 percent allowable error. This is where the experience level of the engineer is important in knowing what or what not to include in the analysis and knowing what upper-end average cost can be used.

Timing of the project is a significant consideration: many projects have fallen victim to financial disaster because of changing markets, the inherent effects on interest and carrying costs, fluctuating cost of money, rework of improperly designed or constructed features, and poor project management. The only solution is to identify, during the feasibility period, the greatest number of variables and learn as much as possible about their impacts on the project, then schedule and control the process in such a manner that, when the surprises come, they do not destroy the overall profitability of the project. For instance, the land development engineer might consider adding up to 5 to 7 percent of the cost estimate for a project with a shorter than usual construction period, for the design-build project, or for construction that will be adversely affected by the winter months.

The following example problem is intended to show how the rough estimating process can be used for a general large-scale project.

EXAMPLE 1

The owner/developer is considering a proffer to provide 20 percent of the construction cost for an elementary school as part of the residential development project. Before agreeing to this proffer, the owner/developer asks the engineer for an order-of-magnitude estimate of the cost.

In this example, the engineer decides to provide a ballpark or order-of-magnitude estimate by comparing the anticipated school with a recently completed school of similar nature. In doing some research, he finds a school was constructed two years ago in a neighboring jurisdiction for $8.5 million. He is aware that soil and terrain characteristics are similar for the two sites, but that the anticipated student population for the proposed school is one-half that of the reference school. He decides to compare the two schools based on a construction-cost-per-student basis. In other words, he assumes that the cost of a school for one-half the number of students would be 50 percent that of the reference school.

The engineer performs the following calculations:

1. Assume a 6 percent inflation rate per year in construction costs; therefore, the comparison school would cost $9.55 million today (two years of inflation at 6 percent.).

2. Assume for this estimate that a school serving half the number of students would cost 50 percent of the $9.55 million, or $4.78 million. The engineer decides to round this to $4.8 million.

3. Assume that the school will be constructed at the end of the development phasing of the project (five years from today). At an assumed inflation rate of 6 percent per year, the final cost, in five years, for the school is $6.42 million.

4. To allow for errors in the assumption that school cost is directly related to school population, and to recognize that the differences in site characteristics can influence the costs substantially, he assumes a 25 percent contingency. The cost for the new school is then estimated to be $6.42 million ± 25 percent, or a range of $4.8 to $8.0 million

5. The engineer provides the cost estimate of $4.8 to $8.0 million to the developer. Since the developer is considering offering 20 percent of the cost, he can consider a future obligation of between $964,000 and $1.6 million.

6. The engineer documents his assumptions and the source of his data in a memorandum to the owner/developer and a copy is kept in the project files.

To summarize, ballpark estimates should be understood to represent nothing more than rough approximations and are intended to be quick estimates. They can be refined when more accurate data is available. They can be an important part of any project development in that they enable quick evaluation of some topic without detailed design or cost estimating. They should be prepared or evaluated only by experienced personnel or at the minimum they should be checked by someone with considerable experience.

Too many times these ballpark estimates are taken to be exact, especially when they are underestimated. The contractor, developer, or other land design professional then wonders what went wrong. This is another reason to err on the conservative side.

Detailed Feasibility Estimates. A detailed feasibility estimate should be performed for all land development projects. Many times the feasibility estimate is part of a larger project feasibility study that evaluates availability of services, potential yields, and potential environmental impacts along with other important factors. If a ballpark estimate indicates a favorable economic condition, it is always desirable to pursue the development of a more detailed feasibility estimate. This type of estimate utilizes a far more refined estimate of quantities and costs associated with project construction and should incorporate all expenditures, including those for land and construction costs, infrastructure, and off-site construction. It is important that this estimate contain the costs for engineering design and surveying, legal fees, governmental review and permitting fees, and, if appropriate, the cost of borrowed capital.

This estimate is also called a *conceptual* or *budget estimate,* and should be accurate to within 15 to 20 percent of the actual cost. To perform this level of estimate, a preliminary layout of the project with streets, utilities, and lots is needed. Preliminary lots are needed to indicate whether the market price will offset the cost of the development construction costs and still yield a reasonable profit.

It is important to note that attaining additional yield does not always guarantee additional profit. Oftentimes the cost to develop the additional yield is offset by additional infrastructure requirements such as American with Disabilities Act (ADA) compliance, environmental mitigation, or other costs to extend streets and utilities. Example 2, later in this chapter, reinforces this concept.

Feasibility Checklist. In developing a cost estimate at this stage of the project, some design data is needed so that rough takeoffs of quantities can be performed. Some engineers include the cost estimate right on the development plan, so that as the plan changes and becomes more refined, the cost estimate can be updated as well.

Most engineering firms develop a feasibility checklist so that all items are considered even if some are not needed on the particular project. The checklist also makes it easy to compare estimates with other projects and ensures consistency when it comes to quality control/quality assurance checks common at each stage in the design process.

Generally, the following elements are to be included in a feasibility cost estimate:

- Land costs
- Clearing, grubbing, and demolition costs
- Roadway, sidewalk, trail and bike path costs
- Storm drain costs
- Sanitary sewer costs
- Water supply costs
- Other utility (power, gas, and communication) costs
- Lighting, traffic signals, and signage
- Grading and earthwork costs
- Erosion and sedimentation control costs
- Stormwater management system costs
- Landscaping costs
- Recreational facilities costs
- Off-site costs (special costs)
- Permits and bond costs
- Soils (rocks) and geotechnical fees

See the following sections describing each of these elements in detail.

As is evident, the development of a feasibility cost estimate can be time consuming. Care must be taken, however, to not overdetail the estimate at this early stage of design. Actual costs, of course, will not become known until the project design is completed. The estimation of project costs as completely and accurately as possible is essential to the client's decision-making process. The identification of *potential* costs is also critical to allow for alternative planning.

Preliminary Estimates

Preliminary estimates, sometimes referred to as *semidetailed estimates,* although considerably refined from the feasibility estimates, are still preliminary. They are developed from plans that have not yet reached sufficient detail to derive construction costs. These estimates should be accurate to within 10 to 15 percent.

These estimates are usually made after a plan has evolved to a fine-tuned stage but prior to actual preparation of final construction drawings. They can serve as advanced conceptual or advanced budget estimates and are usually accurate enough for making decisions regarding the feasibility of a project or for a decision involving a choice among alternatives within a project.

For preliminary estimates, the development plan or site plan should be drawn to scale, including the preliminary road and utility alignments and in some cases preliminary site grades. These plans can be used to estimate several important design quantities, which when multiplied by the applicable unit costs can provide a fairly good construction cost estimate.

After the preliminary development plans have been approved, detailed engineering and preparation of construction documents commence. There are costs associated with these procedures and they can vary greatly depending on the type of project and client (private or public). An estimate of how much it will cost to complete the final design should be prepared as part of the preliminary cost estimate in order to provide the client with an accurate idea of the project's cost to complete in terms of both design and construction.

A checklist should be prepared listing all cost items; the checklist for the preliminary estimates should be at least as inclusive as that employed for the detailed feasibility estimate. Since the quantities are still in a preliminary stage, a contingency factor of 15 to 20 percent should be added to the bottom-line subtotal, depending on the completeness and accuracy of the plans.

It is critical that the engineer and the client agree on the units of measure to be used for each of the elements included in the estimate. The units of measure may be obtained from a source such as the state department of transportation, department of public works, or any other public-sector entity engaged in construction or bond review/approval. Private projects may not always coincide with public specifications. The developer may require the units of measure in a certain format for loan application purposes or for analysis by the contractors; thus, it is important to have a mutual understanding of the cost estimate format.

The elements that should be included in the preliminary estimate are similar to those in the feasibility estimate, only they are based on the more complete plans. The elements to be included are described in the following subsections.

Land Costs. Land costs are usually expressed in dollars per acre and are provided by the owner. This is the line item within the estimate where the initial cost or price paid to the former owner for the parcel is accounted. Since the price is usually determined on an area basis, it is critical that a complete boundary survey be done to determine the exact parcel size. Boundary surveys are described in detail in Chapter 13. It is important to note here that the cost for the boundary survey is a land cost and should be included in the cost estimate.

To be complete, the cost of the deed, title insurance, and any transfer taxes should be included in the estimate. Real estate commissions are usually paid by the seller, but this should be verified, since they can be as high as 6 to 8 percent of the selling price.

Possible rezoning, special exceptions, and other amendments or planning processes that are required to permit the desired land use are another cost component under the land cost. For these actions, usually the new landowner's legal team fees and the cost of any studies (soils, Phase I ESA, etc.) and design fees through the entitlement approval are the main cost considerations.

Clearing, Grubbing, and Demolition Costs. Typically, the cost of clearing, grubbing, and demolition is usually a small portion of the total cost of construction. Most clearing quantities may be estimated on the basis of square yards or, for larger sites, even acres may be appropriate. Depending on the nature of the clearing/grubbing—light woods versus heavy forest versus developed areas such as parking lots—additional costs may be added. Soil remediation or removal to account for organic or other unsatisfactory material should also be accounted for under this item.

Where there are a number of structures to be removed, reused, or salvaged, a demolition plan is recommended in order to provide direction and clarity for the contractor. The cost of the demolition can be difficult to estimate because there may not be a history of unit costs from which to draw; there may be certain environmental regulations that require specific attention—for example, removal of asbestos, lead, or other identified hazardous and contaminated materials from the building or the site, consequently requiring a special subconsultant/estimator. Demolition of buildings should be estimated based on the number and sturdiness of the buildings to be demolished. A contractor expecting to be given the demolition contract may be willing to provide an estimate.

When estimating clearing, grubbing, and demolition costs, it is important for the engineer to have a thorough understanding of the proposed construction process in order to determine the applicable disposal scenarios: waste material may be hauled and disposed of in an appropriate landfill or it may be diverted, salvaged, or recycled on- or off-site. The disposal scenario affects prices assigned to haul routes, landfill tipping fees, and on-site sorting, storage, and treatment of materials. For projects where green building certification is desired, waste management is one of the metrics; a waste management plan addressing the disposal scenarios should be scoped and developed by an experienced professional in order to accurately determine and effectively manage costs in this category.

Roadway, Sidewalk, Trail, and Bike Path Costs. Costs are usually expressed in dollars per linear foot for roads, streets, alleys, sidewalks, trails, and bikeways/multiuse paths, and a lump-sum or square-yard cost for parking lots. This can be misleading, since there could be many separate items included in a linear foot unit cost, including earthwork, pavement, aggregate for the base and subbase course, curb and gutter, and underdrains, along with general street landscaping and sodding. In addition, if appropriate, the costs associated with street and lot lighting, street trees and landscaping, and signs and signals should be included if they are not accounted for as separate items. It should be emphasized that one of the objectives of road design is to obtain an earthwork balance of both the road and the entire site. Without an earthwork balance, the entire project costs can increase significantly.

Pavement costs are usually expressed in dollars per ton of asphalt pavement or per square yard per inch of depth for concrete pavement, and either cost is usually a considerable portion of the roadway cost. For this reason, the development engineer is expected to minimize these costs through innovative design. The traffic count or anticipated traffic load dictate the street width and pavement design. It is important to verify the sidewalk requirements of the jurisdiction early in the design process. Sidewalks both have an economic impact and impose a limitation on lot design. Please note that sometimes sidewalk requirements vary by lot size and street classification. Sidewalk costs can be reduced through judicious use of lot sizes and street types. In some cases, less expensive bikeways/multiuse paths and trails can substitute for sidewalks, but the engineer must be assured that they will be approved by the jurisdiction.

Storm Drain Costs. Storm drain costs are usually expressed in dollars per linear foot of constructed pipe or on a per-structure basis for items such as inlets, manholes, and junction boxes. Quantities for storm drain items including inlet and outlet structures as well as conveyance items (pipes, swales, ditches) should be derived directly from the preliminary plan.

Included in this cost is the pipe itself, culverts, inlets, manholes, headwalls, endwalls or end sections, riprap or other outlet protection devices such as plunge pools or energy dissipators, special drainage structures, underdrains, box culverts, additional vertical depth (excavation and structure sections), rock excavation, and special pipe bedding if needed. Additional costs can encompass backfilling and any site restoration costs, including seeding or sodding if the pipe is placed outside the roadway section. Costs of storm drains can be reduced through implementation of low-impact development (LID) techniques including provisions for porous pavement or other infiltration facilities, when feasible, especially for parking lots; use of natural channels/swales; utilizing the minimum adequate pipe size; using the least number of drainage structures; and setting pipe depths as shallow as possible.

If the proposed storm drain crosses existing utilities, which is common in developed areas, the vertical locations must be thoroughly investigated to ensure system compatibility. If there is a conflict in vertical locations, redesign and/or relocation efforts must be scoped and included in the cost estimate as early as possible. Utility relocation fees are usually substantial; thus, they should be identified during the planning and design process to be estimated accurately.

Sanitary Sewer Costs. Sanitary sewer costs are usually expressed in dollars per linear foot. In some cases a land development project may require a sewage treatment facility or an existing facility may require enhancements due to the construction of the project. To accommodate future development, it may be necessary to install a sewer main with a capacity exceeding the need of your subdivision. In cases when excess capacity is required, the responsible agency should participate in the cost sharing.

The basic sanitary sewer costs include the piping, laterals to the property line (house connections), manholes, drop connections, ejection pumps, and special structures. Restoration costs such as seeding and/or sodding should be included if the pipe is placed outside the roadway section. As with storm drains, costs for sanitary sewers can be reduced by keeping pipe lengths and sizes to the minimum, locating the trenches at shallow depths, and minimizing the number of structures. Additional cost items include rock excavation, roadway crossings, additional vertical depth (excavation and structure section), and jacking/boring/tunneling. Existing utility crossings must be considered and accounted for as previously described under "Storm Drain Costs."

Recently, emerging green building techniques have encouraged the on-site treatment and reuse of gray/blackwater, thus reducing the number of conventional sanitary sewer and sewerage treatment facilities required. While the conventional costs including impact or tap fees may be removed/avoided, it is equally important to accurately cost the new technologies implemented to treat and reuse the wastewater; costing a sustainable, or green, building sanitary treatment/reuse system requires the engineer to work cooperatively with the MEP engineer to account for all components and ensure the costs are assessed either on the site or in the building and not double counted. Regardless of the design approach to sanitary sewer—conventional or sustainable—the design must be code compliant and accounted for in the estimate. Depending on the technology, manufacturer input is likely the best source for unit price information.

Water Supply Costs. If the water supply company will be installing the water systems, the cost of providing water services should be based on their estimates. If the responsibility for the design and construction of the water supply and distribution system is with the engineering consultant, an estimate must be developed. As with sanitary sewers, costs for water distribution systems are expressed in dollars per linear foot. If a water supply and treatment facility, such as a well, a package plant, or a special pumping facility is needed, it is recommended that the land development engineer utilize the services of an engineer experienced in this specialty to provide the cost estimate. Other items included in the water distribution costs are valves, hydrants, water service line, fire lines, blow off and air releasers, tees, and pumps. Cost minimization methods are similar to those for storm drains and sanitary sewer design, and the elements included in the estimate are pipes, laterals services, fittings, water meters, thrust blocks and anchors, and special structures such as valve vaults. Tap fees should also be accounted for in this cost item.

Other Utility (Power, Gas, and Communication) Costs. Other utility costs such as gas mains, fuel transmission pipelines, electric supply, telephone, fiberoptic, and cable television should be included. There may be a requirement that overhead power and communication lines be relocated underground, thus requiring a conduit system. There may also be a need for equipment such as transformers and substations, which may increase cost and require easement provisions. Some utility companies pay for the installation of their utilities (set transformers and pull cables); some look for the developer to pay costs either entirely or on a prorated basis, depending on the foreseeable development in the community. Given the great variation in practice among different utility providers, the first step in cost estimating this item is to determine design/construction responsibility; often the developer is responsible for design and construction of the pathway (i.e., conduit systems), subject to the utilities' approval and base and aesthetic features such as concrete pads, landscaping, fencing, or other screening devices. Conduit is typically priced on a linear-foot basis, while structures in the conveyance system are priced as "each" or per structure.

The utility companies themselves, which may be either public or private companies, can best supply the cost estimates for their facilities. An estimate should be included for these facilities if feasible. Crossing these existing utilities is typically easily accommodated, since the cover requirements, horizontal, and vertical offsets for these utilities are fairly flexible, as they are not gravity driven. Regardless, relocation costs for other utilities should be examined and accounted for, especially when conduit systems are moved from overhead to underground installations.

Lighting, Traffic Signals, and Signage Costs. The cost of installing traffic signals, signing, lighting, guardrail, striping, and other traffic markings should be included. An estimate of the number needed should be based on the type of features and placement required by the jurisdiction. Lights and traffic signals are typically priced on a per-unit basis, while the associated conduits and wires in between the units are estimated on a linear-foot basis. Signage may be priced by square foot, square yard, or in some jurisdictions on a per-unit basis. Guardrail and striping are linear-foot quantities. Traffic signals and their related equipment should be priced by either a signal contractor or an experienced traffic engineer.

Grading and Earthwork Costs. Earthwork costs for the various infrastructure elements are usually included in the per-foot cost of these elements; however, earthwork costs for things such as mass, rough, and final grading of the streets and lots should be estimated separately. The cost of grading for streets and building pads is based on cutting/filling to the desired elevation and compacting the soil to the specifications of the soils engineer. The cost of grading building pads is charged at a different rate than the rate for grading streets and parking lots, so it should be listed separately on the cost estimate. They are usually expressed in dollars per cubic yard and include cut, fill, topsoil, borrow, and excess (earth hauled off the site). Engineers are directed to Chapter 23 for discussion of the importance of attempting to balance the earthwork on the site.

Earthwork costs can be significant, and earthwork engineering is often not readily understood by developers. Care must be taken during design so that, if possible, phasing of construction can be implemented to construct first in areas of cut so that earth can be moved to areas of fill without a secondary storage step or, in the worst case, earth moved off-site only to be brought back later for fill. Also, accommodations should be made if rock or ground water is shallow on the site. The engineer may consider raising the grade of the proposed site to eliminate the need to rip or blast through rock and may need to include provisions for dewatering, ground water diversion, or soil drying. Earthwork costs at this stage of plan development should be based on the most accurate earthwork model available (see Chapter 23 for earthwork methodologies).

Erosion and Sedimentation (E&S) Control Costs. Cost elements include sediment traps and basins, straw and maintenance bales, silt and super silt fence, berms, gravel for truck wash facilities, inlet protection devices, riprap, dewatering and pumping facilities, seed and sod, and erosion control matting. Similar to other elements of design, proper phasing of construction activities can minimize the cost of these facilities. Many jurisdictions require these items to be bonded similar to other public infrastructure components because of the environmental and aesthetic importance of proper erosion and sediment controls. Thus, in addition to the actual construction cost of these facilities, a further bond amount may need to be included in the estimate. Typically, costs to prevent erosion and implement sedimentation control run up to 3 percent of the total construction cost.

Stormwater Management System Costs. Similar to erosion control, jurisdictions are adopting more stringent stormwater management system requirements. In some cases these systems can equal or exceed the costs of the storm drainage system. Included in this item are the costs for both water quality and quantity control facilities. Given the wide range of facility types from natural systems including detention and retention ponds, bioretention gardens/basins, and infiltration trenches to manufactured or technology-based systems such as sand filters, oil/grit separators, and filter inserts, pricing these facilities is highly specific and difficult to generalize.

Natural systems must be priced to include excavation, grading, and embankment construction as well as spillway and outlet structures, inlet and outlet protection, underdrains and dewatering devices, landscaping, and access provisions including roads, paths, fencing, gates, and signage. Most of these items are unit quantities; however, there is a wide range of data available for cost estimating specific SWM facility types (bioretention, infiltration trenches, wet ponds, etc.) on a cubic-yard, square-yard, or acre-foot basis. When it is jurisdictional or client preference to estimate in this manner, the unit prices should be verified, if possible, with contractors experienced in the construction of these types of facilities.

The costs for manufactured systems are best garnered directly from the vendor; the engineer should inquire about the system cost and delivery and installation costs. Costs for additional or supplemental features such as manholes, inlets, underdrain, signage, and maintenance access provisions may still need to be estimated separately.

During the design of the project, system costs can be minimized by carefully placing facilities where they can serve both as a stormwater management facility and as a site amenity. Often a combination of devices is necessary to meet applicable requirements, and it is the responsibility of the engineer to optimize these features, given the goals and intents of the development program, as well as the cost of the various facilities.

Landscaping Costs. Cost estimating in landscaping applications is best approached by breaking down the landscape plan into components such as shade trees, ornamental trees, shrubs, perennials, annuals, ground covers, sod, seeding, and mulch. Other landscape architecture elements that are commonly coordinated with landscape plans include hardscape and architectural items such as gravel, brick and concrete paving, fencing, custom signage, and lighting.

Most plant material, including trees, shrubs, perennials, and annuals, is measured on a per-unit basis. Seeding applications are typically estimated based on an area of coverage and/or the specified application rate. Hardscape, including pavers (brick, concrete, or asphalt), is estimated based on area—typically in square feet or square yards, depending on the application. Fences are measured in linear feet, and retaining walls or other decorative walls are usually included based on square face footage. Topsoil, mulch, and other soil products are volume based quantities—cubic feet or yards. Specialty aesthetic features such as signage and lighting can vary greatly depending on the specific application and quantity and may be measured per unit or, often, as a lump sum for the installation. Quantities can usually be determined from the plant schedule and details and/or the preliminary plan. To ensure accuracy, quantities should be reviewed after construction documents are prepared.

RSMeans Landscape Cost Data and *RSMeans—Site Work & Landscape Cost Data* are examples of the widely accepted industry publications that price landscape work items and associated costs. In addition to the proposed construction items, the cost estimate may need to include a cost for existing plant material to be maintained and any special treatment associated with the preservation effort (trimming, aeration, etc.) as well as repairs to any landscape items damaged during construction or that die off during the warranty period.

Recreational Facilities Costs. Many times the development of a project includes the cost of recreational facilities. These may be proposed by the developer to enhance the project's vitality or in an attempt to seek support for approval of the development. In addition, the approving jurisdiction may impose additional recreational facilities during the entitlement process. These facilities may serve only the proposed development or additional users outside the project. For example, the jurisdiction might require the dedication of land for a regional park and require the developer to construct a pond as his or her commitment. The jurisdiction could construct the park features such as trails and buildings, and provide for future maintenance as the public commitment to the park's development. In this example, the pond could serve as the stormwater detention facility for the project and a recreational facility for the jurisdiction. As part of the cost-estimating process, only the developer's costs should be included in the cost estimate. A well-planned development could take advantage of these features through good initial planning and design.

Elements that should be included in the recreational facility costs are park development; sod and/or seeding; earthwork such as mounding, tennis courts, swimming pools, basketball facilities, fencing, and tot lots; and any landscaping elements not previously included. If there is an excess of earthwork in the project, good landscape design, through the creation of sound berms and mounds in the park, can reduce the costs of hauling away excess and unsuitable material. On the other hand, if there were a shortage of fill material, sound landscape design would consider lowering the future park site.

Off-Site Costs (Special Costs). To serve the development with adequate utilities or to adequately direct sewage or stormwater away from the site, many off-site costs can be required of the developer. Good engineering design should identify the condition of downstream outfalls and determine any requisite improvements required to these systems. Many times these enhancements are the responsibility of the developer and should be included in the estimated cost of the project. Care must be used not to prematurely state that these are 100 percent the responsibility of the project development. In some instances, the case can be made that these benefit adjacent future development or the public in general, and therefore, the costs should be shared. At this stage in the development, the engineer preparing the cost estimate can make an assumption and use this assumption in the calculation, but footnotes should be made to identify the assumption and a brief justification of the assumption.

Special or off-site costs that should be considered are those for streets and/or street widening and reconstruction, traffic controls, signalization, bridges, sidewalks, hike/bike trails, stormwater management facilities (in particular, regional facilities), landscaping, lighting, and signs.

Permit and Bond Costs. On most projects, permits from the local, and sometimes the state, governments must be obtained before construction can commence. Tap or hook-up fees are common for most utilities and should be included under this item if not accounted for under the individual utility costs. Many kinds of construction activities require inspections both during and after construction that are intended to provide consistency in construction activities and to provide for safety during both construction and in system use.

The permits associated with developing a tract of land can be numerous. The cost associated with procuring the vast number of permits must be accounted for. Permits are usually required for grading, paving, drainage, sewer connections, water connections, electrical and gas connections, wetlands delineation and encroachment, and forest or tree stand delineation, clearing, and impacts. The local and state governments could require additional permits based on regional considerations. Generally, the fees charged by the reviewing agency are structured to recover their costs for review of plans and inspection, but some governments use these fees as a way of securing additional general revenue. In any case, it is the responsibility of the engineer to carefully identify all fees for the required permits, since these fees and permits can be in the range of 20 to 25 percent of the physical construction costs for the project (excluding land acquisition and house construction costs).

On most projects of substantial size, the developer and/or contractor must post a surety bond and in some cases a conservation bond (covering erosion and sediment control, landscaping, and other natural site features to be installed or protected) to ensure adequate construction quality. While this bond is returned at the end of the project, it can involve a loan from a bonding company or, at a minimum, involve lost interest for the construction period. Many jurisdictions now permit the potential partial release of bonds as project phases are completed. Although this does not affect cost estimates, it can substantially reduce the developer's cost, and if the engineer can identify this possibility and move promptly to get the partial bond release, the client can save in terms of lost interest cost.

Professional Fees. As part of any project, professional consultant fees should be included in any cost estimate, since they can represent as much as 15 percent of the project cost. These fees include the engineer's, surveyor's, geotechnical, environmental consultant's, construction manager's, and architect's fees, as well as attorney expenses. Generally these fees are based on the cost of the facilities, factored by the complexity of the project. Attorney fees vary widely from a lump sum for the entire project to an hourly fee. Whatever method is chosen to estimate the cost, the assumptions should be clearly stated in the report that accompanies the estimate.

The engineering and architectural fees can be divided into two categories: (1) design development (usually up to and including the entitlement process, surveying, planning efforts, and preliminary engineering) and (2) final design and construction document preparation and permitting services. Construction phase services are typically an add-on or separate category and should be identified as such in the cost estimate. Typically, professional fees vary between 7 and 15 percent of the total project cost.

Financial Fees. Financial fees in the cost estimate are best left for the client to estimate, based on his or her particular situation. Financial fees are usually based on a percentage of borrowed money. Interest charges during the life of the project can be substantial if the project has a long history from purchase of land to completion of construction. The cost of financing may range from 5 to 20 percent of the total project cost.

Contingency Allowance. Allowing for contingencies is an elemental part of the estimate of project cost to allow for unforeseen conditions and for variances in design elements. There is no generally accepted percentage. The amount varies by the complexity of the project, the anticipated time for completion, and the individual idiosyncrasies of the engineer (i.e., conservative versus liberal). It is common to see contingencies used from 5 to 30 percent. If the engineer is unsure of the contingency to allow, it is recommended that a minimum of 15 percent be utilized. If the client disagrees, the amount can be altered by the client. However, it is recommended that the engineer's original contingency used by the engineer be documented in the project files. If the project is to be phased over numerous years, the cost of escalation should affect the contingency; alternatively, a separate line item can be included for inflation.

The notes to the cost estimate are particularly important. Any assumptions used in making the estimate should be clearly explained, including indication of whether the costs used are at current value or include an inflation factor.

Other Miscellaneous Costs. Other miscellaneous costs should be included if pertinent. Consideration should be given to such items as marketing analysis, maintenance cost of project elements constructed but not accepted by the operating agency until later, and other costs not accounted for in any previous section. These might include such items as environmental mitigation and special landscaping costs.

The engineer should elaborate on the possible costs that are not included, such as sound walls, environmental impact reports, and soil reports. Where the facilities required are oversized, the jurisdiction may give partial reimbursement to the developer for improvements larger than what are needed to serve the project. When this is the case, the anticipated reimbursement should be described. Costs that constitute refundable deposits, such as are sometimes required for water meters until the building is occupied, should be listed. Other costs include meeting current fire safety codes; providing handicapped access (current ADA requirements); other building code requirements retroactively required for existing buildings as part of the development subject to reconstruction/remodeling; making temporary vehicle, bicycle, and pedestrian access modifications to accommodate construction activities; and making parking modifications required to accommodate the contractor during construction. Restricted site access, limited material storage space, and a remote location certainly add to the cost of a project. For those projects that require an archeological survey, an additional fee of up to 1 percent may be needed to cover these costs.

Soils (Rocks) and Geotechnical Fees

The types of soils found on the project site can affect project construction costs because of the need to change the existing soil characteristics. If a significant portion of the soils cannot be made compatible with the proposed development program, the costs for replacing the existing soils can be extreme. Excavation and the provision of sufficient suitable backfill can also increase costs.

The presence of rock on the proposed site will also have a tremendous effect on the construction cost. If excavation of rock is required, blasting may be necessary.

Summary. The purpose of preliminary engineering is to acquire approvals from the permitting jurisdiction to determine the problems that will affect the project and the cost to construct it. Among other uses, preliminary estimates are valuable for obtaining developer loan applications, developing cash flow schedules, and fine-tuning preliminary market prices for product.

These costs may (and should) be estimated again throughout the design process, but it is imperative to be thorough from the beginning, as the economic success of a project is often closely tied to the preliminary cost estimates.

Construction Estimates

Construction cost estimates, also referred to as *detailed estimates,* are generally developed only after the construction plans have been approved by all necessary agencies. Quantity takeoffs for work to be performed are often made before all final approvals are obtained. Therefore, it is critical that all takeoffs and estimates be dated and referenced to a dated plan sheet. This ensures that the final construction cost estimate is based on the final approved plans used for construction.

Construction cost estimates can be performed by different professionals, but, as is always the case, should be reviewed and approved only by persons with many years of experience to ensure the thoroughness and credibility of the estimate. It is important that somewhere in the process an individual with knowledge of the details of construction work perform a constructibility review and either develops the estimate or checks the efforts of others. This knowledge is best acquired through actual experience in construction work. It is also important for the estimator to be able to visualize the various construction phases of a project and incorporate equipment needs, materials needed, and the handling of these during construction.

It is important during the development of the construction cost estimates that the latest available information be used. An experienced engineer should keep an updated file with recent bid information on materials, labor, and the availability of construction items. Later in this chapter, a list of possible sources for this information is provided. The developer and design engineer need to be wary of potentially outdated data. This can include infrastructure record drawings on file with public entities for the project's location, previous surveys, aged geotechnical reports, and aged cost data for previous similar projects. The design engineer should make recommendations to the developer regarding the need to obtain more up-to-date information. Some of the information can be verified through new surveys and site visits. Other information about such things as types and quantity of soil and rock, fiberoptic cables, and gas lines can be more difficult or costly to verify because there are few surface clues to be found. Even if these are updated, the percentage of contingency should be reviewed based on the comfort of the developer and design team with the procured information.

In general, the construction estimate should include the quantities and unit costs of all items needed to construct the project. The construction cost estimate can be used for some of the same items as identified for the preliminary estimate, such as loan applications, cash flows, and the development of market prices. In addition, this estimate can provide the owner/developer with a reasonably accurate guide for the amount of funding needed to complete the project.

After the plans are complete, exact measurement of construction materials can be made. The lengths of curbs, areas of roadways and landscape, tons of asphalt, and all the materials and activities needed to construct the project are now known and can be shared among the design team to verify preliminary estimates prior to bidding or release of construction documents. Contractors will also make an estimate and determine what their costs of construction will be before they bid on the project. If the engineers' and the contractor's estimates are very different, the reason should be understood. A poor economy may prompt contractors to bid low because of the need for work, but the developer should be leery of contractors whose bids are very low—that is likely to indicate a poor understanding of the work involved. If contractors' bids come in high, the developer may want to seek out more contractors to bid on the project or ensure the design team has not made an error(s) in their estimate. Sometimes sharp price fluctuations (e.g., of steel or crude oil) may significantly affect the unit price of items such as structural steel, reinforcement, and asphalt.

Many times the developer will ask contractors for bids on selected portions of the project, including infrastructure, grading, and roadway/street construction. The construction cost estimate should be formatted so that the data needed to compare actual bid prices with the estimate is easily obtainable. Wide disparities in the bids, if several bids are being compared, usually indicate a lack of clarity in the plans, specifications, or instructions to the bidder. One or two marked deviations from all the bids, however, usually indicates some oversight or lack of understanding by the bidder.

The construction cost estimate should be accurate within 5 to 10 percent. The accuracy depends on the complexity of the plans and specifications and on how current the bid data used to develop the unit costs is. Errors in the design plans can greatly affect the accuracy of the cost estimate. Backcharges and extras by contractors due to incomplete and/or inaccurate plans increase costs significantly.

Since construction cost estimates utilize quantity takeoffs from drawings to be used in constructing the project, the cost estimate is obviously only as accurate as the quantities to which costs are assigned and the accuracy of the estimated cost. In addition, the engineer must recognize that multiplication of numbers, as performed when applying unit cost to quantities, can result in magnification of errors. Propagation of errors in the product of two independent variables, where *A* and *B* are the independent variables and ε is the uncertainty or error in the variables, is shown in Equation 29.1.

$$C \pm \varepsilon_C = (A \times B)\sqrt{(A \pm \varepsilon_B)^2 + (B \pm \varepsilon_A)^2} \qquad (29.1)$$

For example, suppose the estimate for excavation is 10,000 *CY* ± 20% and the cost is \$10.80 ± 10%. Using Equation 29.1, the accuracy of the cost is:

$$\begin{aligned} &(10{,}000 \pm 20\%) \times (\$10.80 \pm 10\%) \qquad (29.2)\\ &= (10{,}000 \pm 2{,}000) \times (\$10.80 \pm \$1.08)\\ &= (10{,}000 \times 10.80) \pm \sqrt{(10{,}000\,(1.08))^2 + (10.70\,(2{,}000))^2}\\ &= 108{,}000 \pm 24{,}150\\ &= \$108{,}000 \pm 22.4\% \end{aligned}$$

Note that although the estimated range (i.e., error) in quantity is 20 percent and the estimated range (i.e., error) in the cost is 10 percent, the overall accrued error is 22.4 percent.

When two independent variables are added together, the accrued error is represented by Equation 29.3.

$$C \pm \varepsilon_C = (A + B) \pm \sqrt{\varepsilon_A^2 + \varepsilon_B^2} \qquad (29.3)$$

Table 29.1, generated from Equation 29.1, provides the expected error, given the errors of the two independent variables. For example, the error of 22.4 percent calculated using Equation 29.2 can be obtained by entering 20 percent for variable *A* and reading across to the 10 percent column of variable *B*. Table 29.2 shows how errors are accrued when numbers are multiplied and added together. Care must be used to minimize the errors; otherwise, they can be compounded throughout the estimate.

It is imperative that every item indicated in the construction plans be included in the estimate, since the contractor installing these items will most surely include it. It is especially important for the construction cost estimate to try and give at least a guesstimate of contingent items such as rock excavation, pipe bedding, excavation, and removal of unsuitable material, undercutting, and other similar items. These items need to be recognized initially should they become necessary in the actual construction they have been planned for, although they were not specifically indicated on the construction drawings. When such guesstimates are included, it is recommended that they be footnoted to differentiate them from the normally more accurate cost items.

It is recommended that engineers utilize a standard checklist and a statement cost estimate sheet or develop ones if they do not exist. Existing computer programs for data manipulation work well to standardize the form and can perform all arithmetic functions automatically. When computerized, they can be the basis of a method of filing historic costs. A typical checklist is shown in Figure 29.1. A standard cost estimate sheet is shown in Figure 29.2.

For construction cost estimates, a contingency of 10 percent is usually employed, depending on the source and timeliness of the unit costing.

TABLE 29.1 Percent Error Expected in the Product of Two Independent Variables

% Error in Variable *A*	Percent Error in Variable *B*: 0	5	10	15	20	25	30
0	5	5.0	10.0	15.0	20.0	25.0	30.0
5	5	7.1	11.2	15.8	20.6	25.5	30.4
10	10	11.2	14.1	18.0	22.4	27.0	31.6
15	15	15.8	18.0	21.2	25.0	29.2	33.6
20	20	20.6	22.4	25.0	28.3	32.1	36.1
25	25	25.5	27.0	29.2	32.1	35.4	39.1
30	30	30.4	31.6	33.6	36.1	39.1	42.5

TABLE 29.2 Compounding of Errors Showing Quantities Times Unit Costs

Item	Quantity	Unit Cost	Total Cost	Accuracy ($)	Accuracy (%)
Excavation	10,000 CY ± 20%	$10.80 ± 10%	$108,000	$24,150	±22%
Concrete sidewalk	250 LF ± 15%	$40.00 ± 20%	$10,000	$2,500	±25%
36-inch-diameter concrete pipe	320 LF ± 10%	$90.00 ± 15%	$28,800	$5,192	±18%
			$146,800	$31,842	±21.7%

Table 29.3 shows a procedure list as used by a typical land development engineering group. It is intended to provide a framework for proceeding through the preparation of a cost estimate. Not all items will be needed for every estimate; however, all should be considered.

VARIABLES AFFECTING COST

Many variables affect the cost of a project. As the engineer is preparing the cost estimate, he or she should be aware of whether any of the following items are significant enough to be investigated in more detail: size of the job, location of the site, season, current state of the economy, financial factors, cost of the property, type of the zoning and use, whether any utility or road relocation is involved, whether any unusual structures (e.g., retaining walls, bridges) are involved, and an inflation factor.

Size and Complexity of the Project

The size and complexity of the project can have a significant effect on the cost of physical improvements, particularly when considered on a cost-per-unit basis. Smaller sites can require a nonproportional cost for infrastructure improvement, particularly with respect to streets and underground utilities. Quantity discounts that are given for construction materials may not apply for smaller sites. Furthermore, it is important to note that attaining additional yield—for example, more housing units—does not always guarantee additional profit. This is especially true if the cost to develop the additional yield is offset by additional infrastructure costs. The following example demonstrates that this condition could occur.

EXAMPLE 2

After a 60-unit single-family development project is into the design stage, the client (developer) considers an offer to purchase an adjacent site to add to the total project. The site would add 12 units and, due to its location, would enhance the attractiveness of the project. However, the parcel of land being considered has steep terrain and must be elevated by fill. To accommodate the additional units, the sanitary sewer and storm drain system for a portion of the initial site (Phase I) must be constructed deeper for 25 percent of the units, at an additional cost of $2000 per unit. How should you as the developer's engineer, analyze the situation and what advice should you give your client?

SUBDIVISION NAME ____

(Section, Lot No.)

Contract/Work Order No. ______________________________ Date ________________

____

Signature

***All cost estimates shall be prepared by a senior engineer who will include all the following items in the cost estimate. (If not, briefly describe why!)

1. _______ **Clearing and grubbing**

2. _______ **Excavation:**
   - a. _______ Class A, Rock excavation
   - b. _______ Class B, Regular
   - c. _______ Class C, Wet
   - d. _______ Class D, Haul
   - e. _______ Class E, Borrow
   - f. _______ Class F, Shrinkage

3. _______ **Sheeting and shoring**

4. _______ **Utility lines**
   - a. _______ Sanitary sewer lines
   - b. _______ Storm sewer lines
   - c. _______ Underdrains
   - d. _______ Waterlines
   - e. _______ Electric
   - f. _______ Gas
   - g. _______ Lighting
   - h. _______ Remove and replace pavement

5. _______ **Utility lines should be estimated considering the following:**
   - a. _______ Depth of excavation
   - b. _______ Gravel underdrains
   - c. _______ Size and classification of main
   - d. _______ Linear foot quantities
   - e. _______ French underdrains
   - f. _______ Sheeting and shoring
   - g. _______ Hand excavation
   - h. _______ Rock excavation
   - i. _______ Wet excavation

6. _______ **Concrete work**
   - a. _______ Curb and gutter work
   - b. _______ Sidewalks
   - c. _______ Wingwalls
   - d. _______ Cut-off walls
   - e. _______ Riprap
   - f. _______ Reinforced concrete
   - g. _______ Miscellaneous concrete work
   - h. _______ Retaining walls

7. _______ **Pavement**
   - a. _______ Subbase
   - b. _______ Base
   - c. _______ Paving - Asphalt/concrete
   - d. _______ Paving - Portland cement

8. _______ **Seeding**

9. _______ **Sodding**

10. _______ **Driveways and driveway aprons**

11. _______ **Guardrails, reflectors**

12. _______ **Painting**

13. _______ **Lighting**

14. _______ **Engineering**
    - a. _______ Engineering design
    - b. _______ Surveying stakeout

15. _______ ***Point out in cover letter items not included, such as:**
    - a. _______ Land costs
    - b. _______ Interest costs
    - c. _______ Inspection costs
    - d. _______ Builder's overhead
    - e. _______ Legal fees
    - f. _______ Onsite work
    - g. _______ Planning and preliminary engineering work
    - h. _______ Advertising and public relations
    - i. _______ Permits and bonds.

16. _______ **Riprap**

17. _______ **Gravel - various kinds**

18. _______ **Structural steel work**

19. _______ **Timber construction**

20. _______ **Temporary construction**
    - a. _______ Access roads
    - b. _______ Diversion ditches
    - c. _______ By-passes

21. _______ **Silt control**
    - a. _______ Seeding
    - b. _______ Silt basin

22. _______ **Contingency item (10%)**

FIGURE 29.1 Cost estimate checklist.

Project Name ______________________________

Prepared By ______________________ Date ____________

Checked By ______________________ Date ____________

Item	Quantity	Unit	Unit Price	Cost
A. Clearing and Grading				
1. Clearing and Grubbing	______	Acre	______	______
2. Disposal	______	L.S.	______	______
3. Excavation (cut)	______	C.Y.	______	______
4. Embankment (fill)	______	C.Y.	______	______
5. Borrow	______	C.Y.	______	______
6. Spoil/Disposal	______	C.Y.	______	______
7. Topsoil Removal/Storage	______	C.Y.	______	______
8. ______________	______	____	______	______
	Sub-Total for Clearing and Grading			______
B. Erosion/Sediment Control				
1. Earth Berm	______	L.F.	______	______
2. Perimeter Dike	______	L.F.	______	______
3. Interceptor Dike	______	L.F.	______	______
4. Filter Fabric Fence	______	L.F.	______	______
5. Gravel Filters: (Excl. filters with basins)	______	C.Y.	______	______
6. Inlet Sediment Traps	______	Each	______	______
7. Sod	______	S.Y.	______	______
8. Seeding (disturbed area minus pavements and buildings)	______	S.Y.	______	______
9. Sediment Basins (including filters)	______	Each	______	______
10. Wash Rack (incl. water service)	______	Each	______	______
11. ______________	______	____	______	______
	Sub-Total For Erosion/Sedimtent Control			______
C. Streets				
1. Bituminous Concrete Surface:				
1"	______	S.Y.	______	______
2"	______	S.Y.	______	______
2. Base Course: 6" Aggregate	______	S.Y	______	______
3" Bit. Conc.	______	S.Y.	______	______
3. Aggregate Sub-base	______	C.Y.	______	______
4. Cement Treated Aggregate	______	C.Y.	______	______
5. Cement Treated Sub-grade	______	C.Y.	______	______
6. Surface Treatment	______	S.Y.	______	______
7. Gravel Shoulder	______	S.Y.	______	______
8. Curb & Gutter	______	L.F.	______	______
9. Header Curb	______	L.F.	______	______
10. Median Curb	______	L.F.	______	______
11. Curb Cut Ramps	______	Each	______	______
12. Commercial Entrance	______	L.F.	______	______
13. Driveway Entrance	______	Each	______	______
14. Guard Rail	______	L.F.	______	______
15. Traffic Barricade	______	Each		

FIGURE 29.2 Cost estimate sheet.

	16. Edge Delineators		______	Each	______	______
	17. Sidewalk (4' wide, concrete)		______	L.F.	______	______
	18. Rock Excavation		______	C.Y.	______	______
	20. Soil Testing (Road)		______	L.F.	______	______
	21. ______		______	______	______	______
				Sub-Total for Streets		______
D.	**<u>Storm Sewer</u>**					
	1. Easement Clearing & Restoration		______	L.F.	______	______
	2. Pipe RCCP, Classes II-IV:					
		15"	______	L.F.	______	______
		18"	______	L.F.	______	______
		21"	______	L.F.	______	______
		24"	______	L.F.	______	______
		27"	______	L.F.	______	______
		30"	______	L.F.	______	______
		33"	______	L.F.	______	______
		36"	______	L.F.	______	______
		42"	______	L.F.	______	______
		48"	______	L.F.	______	______
			______	L.F.	______	______
	3. Pipe, CMP:	15"	______	L.F.	______	______
		18"	______	L.F.	______	______
		21"	______	L.F.	______	______
		24"	______	L.F.	______	______
		27"	______	L.F.	______	______
		30"	______	L.F.	______	______
		33"	______	L.F.	______	______
		36"	______	L.F.	______	______
			______	L.F.	______	______
	4. Endwall	15"	______	Each	______	______
		18"	______	Each	______	______
		21"	______	Each	______	______
		24"	______	Each	______	______
		27"	______	Each	______	______
		30"	______	Each	______	______
		33"	______	Each	______	______
		36"	______	Each	______	______
		______	______	Each.	______	______
	5. End Section	15"	______	Each	______	______
		18"	______	Each	______	______
		21"	______	Each	______	______
		24"	______	Each	______	______
		27"	______	Each	______	______
		30"	______	Each	______	______
		33"	______	Each	______	______
		36"	______	Each	______	______
		42"	______	Each	______	______
		48"	______	Each	______	______
		______	______	Each	______	______
	6. Endwall		______	Each	______	______
			______	Each	______	______

Figure 29.2 *(Continued)*

7. Curb Inlet	________	Each	________	________
8. Other Inlets	________	Each	________	________
	________	Each	________	________
9. Junction Box JB-1 Pipe size: ____	________	Each	________	________
____	________	Each	________	________
10. Manhole	________	Each	________	________
11. Modified Structure	________	Each	________	________
12. Connect to Existing Structure	________	Each	________	________
13. Remove Existing Structure	________	Each	________	________
14. Pavement Restoration	________	S.Y.	________	________
15. Curtain Wall	________	C.Y.	________	________
16. Concrete Cradle/Encasement	________	L.F.	________	________
17. Concrete Anchors	________	C.Y.	________	________
18. Paved Ditch	________	C.Y.	________	________
19. Sod Ditch	________	S.Y.	________	________
20. Rip Rap: Class I Ungrouted	________	C.Y.	________	________
Class I Grouted	________	C.Y.	________	________
Class II	________	C.Y.	________	________
21. Piling	________	L.S.	________	________
22. Box Culvert (compute Cost on Box Culvert Computation Form)	________	L.S.	________	________
23. Underdrains	________	L.F.	________	________
24. ____________________	________	____	________	________
		Sub-Total for Storm Sewer		________

E. Sanitary Sewer

1. Easement Clearing & Restoration	________	L.F.	________	________
2. Pipe,(Including 0-8' Trenching and Select Fill): 8"	________	L.F.	________	________
10"	________	L.F.	________	________
3. Pipe, RCCP (Including 0-8' Trenching and Select Fill): 8"	________	L.F.	________	________
10"	________	L.F.	________	________
4. Pipe, Ductile Iron (Including 0-8' Trenching and Select Fill): 8"	________	L.F.	________	________
10"	________	L.F.	________	________
5. Extra Trenching (Not includng Pipe): 8'-12'	________	L.F.	________	________
12-16'	________	L.F.	________	________
16'+	________	L.F.	________	________
6. Manhole (All Manholes) 0'-8'	________	Each	________	________
(Depth over 8') 8'+	________	V.F.	________	________
7. Drop Connection	________	V.F.	________	________
8. Concrete Encasement	________	L.F.	________	________
9. Concrete Cradle	________	L.F.	________	________
10. Concrete Anchors	________	C.Y.	________	________
11. Rock Excavation	________	C.Y.	________	________
12. Sheeting and Shoring	________	L.S.	________	________
13. Pavement Replacement	________	L.F.	________	________
14. Laterals: 4"	________	L.F.	________	________
5"	________	L.F.	________	________
15. Risers	________	V.F.	________	________

FIGURE 29.2 *(Continued)*

	16. "T" or "Y" Connection:				
	8" x 4"		Each		
	8" x 5"		Each		
	10" x 4"		Each		
	17. Lateral Connection to Manhole		Each		
	18. Connect to Existing Structure		Each		
	19. Aerial Pipe Supports		L.S.		
	20. Boring or Jacking		L.F.		
	21. Select Fill Material		C.Y.		
	22. ____________		_____		
			Sub-Total for Sanitary Sewer		
F.	**Water Line**				
	1. Easement Clearing & Restoration		L.F.		
	2. Pipe, DIP: 3"		L.F.		
	4"		L.F.		
	6"		L.F.		
	8"		L.F.		
	10"		L.F.		
			L.F.		
	3. Valve 3"		Each		
	4"		Each		
	6"		Each		
	8"		Each		
	10"		Each		
			Each		
	4. Fittings (Tees, Bends Crosses, Reducers, and Offsets)		LB.		
	5. Copper Water Service (Includes Curb Stop) Note: Tap fee may cover this item		L.F.		
	6. Wet Tap		Each		
	7. Fire Hydrant		Each		
	8. Blow-off		Each		
	9. Air Release		Each		
	10. Rock Excavation		C.Y.		
	11. Boring and/or Jacking		L.F.		
	12. Pavement Restoration		L.F.		
	13. Shoulder Restoration		L.F.		
	14. Concrete Anchor/Encasement		C.Y.		
	15. Concrete Cradle		L.F.		
	16. Relocate Existing Hydrant		Each		
	17. Sheeting and Shoring		L.F.		
	18. Select Fill Material		C.Y.		
	19. ____________		_____		
			Sub-Total for Water		
G.	**Miscellany**				
	1. Septic Field		L.S.		
	2. Pump		Each		
	3. Monuments and Pipes		L.S.		
	4. Monuments and Pipes		Lot		
	5. Walkways and Trails: 4' Asphalt		L.F.		
	8' Asphalt		L.F.		
	4' Gravel		L.F.		
	4' Woodchip		L.F.		

FIGURE 29.2 (*Continued*)

6. Landscaping	_______	L.S.	_______	_______
7. Recreational Amenities	_______	L.S.	_______	_______
8. Screening	_______	L.S.	_______	_______
9. Fencing	_______	L.S.	_______	_______
10. Retaining Wall	_______	L.S.	_______	_______
11. Well	_______	Each	_______	_______
12. Street Sign	_______	Each	_______	_______
13. Wheel Stops	_______	Each	_______	_______
14. _______________	_______	_____	_______	_______
		Sub-Total for Miscellaney		_______

H. Total Cost		Cost
1. Sub-Totals:	Clearing and Grading	_______
	Siltation/Erosion Control	_______
	Streets	_______
	Storm Sewer	_______
	Sanitary Sewer	_______
	Water	_______
	Miscellany	_______
	GRAND SUB-TOTAL	_______
2. Engineering & Contingencies (%)		_______
	TOTAL COST	_______

Note: Cost Data Taken from available records.

FIGURE 29.2 (*Continued*)

ANALYSIS AND SOLUTION

You, as the engineer, are aware that the developer is seeking a 12 percent profit, or \$15,000 per unit. You decide to evaluate the additional costs related to the incremental development (Phase II) against the required profit.

First, you determine the required incremental profit:

\$15,000/unit × 12 units = \$180,000 (required profit)

Based on a preliminary evaluation of elevations of the Phase II site, you estimate the cost of the fill required to be \$75,000. You also perform an analysis for incremental infrastructure cost for Phase II and estimate the cost to be \$60,000. You check with the local jurisdiction and find that the additional units in Phase II will increase traffic volumes on the primary access route, which also serves Phase I. The increase in traffic volume will require the road to have a wider cross section, and you estimate the incremental cost of the widening to be \$20,000. The total incremental infrastructure cost for Phase II is \$80,000.

Next, you estimate the additional cost for the deeper sewers in Phase I. You have been told by the developer's contractor that he would estimate the cost to be \$2000 per unit for 25 percent of the Phase I units, or 15 units. This results in an additional cost for Phase I of \$2000/unit × 15 units = \$30,000.

You now compare the total incremental costs to the required profit:

Additional Cost for Fill (Phase II) = \$75,000 (29.4)

Additional Cost for Infrastructure (Phase II) = \$80,000

Additional Cost for Infrastructure (Phase I) = \$30,000

Total Cost = \$185,000

You now prepare a report to your client indicating that, based on your assumptions, he will not achieve the required profit, since the total incremental cost exceeds the required profit by \$5000. You also advise that if any unforeseen costs were incurred that are not included in your evaluation it would make the differential even less appealing. You document your findings and assumptions clearly in the report to the client and include a copy of the report in the project files.

Specifics of Site

Development costs can vary greatly because of the specifics of the site. The provision of services, particularly utility ser-

TABLE 29.3 Procedure for the Preparation of Cost Estimates

All cost estimates shall be prepared by a *senior engineer* who shall, prior to beginning any quantity and cost estimate, undertake the following:

1. Secure the plan that is to be used as the basis for the estimate, and *clearly reference* a set of the plans as the source material upon which the estimate is predicated.
2. Research files and senior company engineers to determine what jobs, if any, have been done in the vicinity of the subject tract.
3. Obtain soil maps or reports of the tract under consideration, if available.
4. Conduct site inspection by physically walking the site, not just a "ride-by."
5. Use a standard cost estimate checklist and itemize each quantity or clearly state why the quantity is not defined.
6. Secure from a reliable source (reputable contractor, current bids, contractor's data report, recent cost estimates) unit costs for all improvements required.
7. Verify that costs secured are installed/finished construction prices.
8. Check all prices with another senior engineer to obtain concurrence on prices used.
9. Prepare chart-form cost estimate detailing type of improvement, quantity, units, unit cost, and total cost.
10. Have addition and multiplication cross-checked by another qualified person.
11. Prepare a cover letter to accompany all cost estimates, making the cost estimate an integral part of the letter (i.e., number of all pages—1 of 4, etc.). In this way the cost estimate should not get separated from the cover letter that qualifies the estimate.
12. The cover letter should enumerate that only those items listed in the cost estimate were considered. Additionally, it should detail those items that were not considered and why.
13. All cost estimates, regardless of how they are prepared, should qualify soil conditions and their possible effect on development costs.
14. All cost estimates must clearly define the source base plan used for the estimate.
15. All cost estimates must show the preparer of same and the date the estimate was prepared, irrespective of closing signature.
16. All cost estimates should be checked by senior staff prior to being sent to the client.
17. All cost estimates should clearly state that costs are based on present-day dollars.
18. All cost estimates should have rounded totals as final figures, which should include a 10 percent contingency factor added in at the end of the estimate.
19. All cost estimates should state the source of unit costs applied to the quantities.
20. Prepare the estimate in the order of construction events.
21. Include a base plan with the cost estimate and letter.

vices, can cause a wide disparity in costs between sites. If potable water, trunk sanitary, and/or storm sewer systems are not readily available, the provision of connections to these utilities can greatly increase construction costs for a project. The reconstruction or widening of a major highway can involve substantial construction costs attributable to the project and can have a serious impact on the per-unit costs.

If earthwork balance cannot be achieved, fill must be borrowed from an off-site source or excavation and embankment material must be exported. These earthwork transportation costs can seriously affect the economic viability of the site. Errors in estimating earthwork can lead to misleading profit percentages, and care must be taken to estimate these costs as accurately as possible. The quantity takeoff estimate has become much more accurate with development of a series of proprietary software packages, which allow for electronic compilation of quantities directly from the engineering design files, specifically for earthwork through comparison of digital terrain models (DTMs).

The political climate, particularly with respect to neighboring parcels, should not be underestimated. Costs to buffer or protect adjacent neighborhoods, using extensive landscaping, sound berms, or walls, can add to the project cost significantly. If possible, these costs should be estimated and included within early feasibility cost estimates.

SOURCES OF UNIT COST DATA

As important as quantities and contingencies are to cost estimating, the accuracy of the cost estimate also depends heavily on the accuracy of the unit cost data. When providing unit cost data for an estimate, it is recommended that the engineer check first with the client owner (or developer) to determine whether a relationship has been established with a reliable local contractor. If one exists, the contractor can provide information on recent bid data on similar projects, which is the best method of estimating unit costs. In some areas, local construction companies form trade associations to evaluate common problems and to promote their work. Frequently, these groups publish listings of recent successful bids. There are also nationally published bid tabulations such as the Bid Reporter and the Contractors Data Report. Many state departments of transportation publish recent bid tabulations from which general information on unit costs can be obtained.

Local public works agencies can also provide information on recent costs. Care must be exercised when using this information, since the construction costs for a public project may be different from those for privately constructed projects. An example of bid tabulation from a local agency is shown in Figure 29.3. In addition, many local governments require performance bonds for private projects. Many public agencies publish a unit price list to be used for the performance bond estimate. An example is shown in Figure 29.4. Care must be exercised by the engineer in using such information, as performance bond unit prices generally are higher than private construction costs, since additional amounts are included to reflect administration and start-up expenses when the agency must step in to complete a project.

In addition, there is published information generally identified as “Guides to Construction Costs.” These include *Building Construction Data* by the RS Means Company, the Dodge Reports published by the F.W. Dodge Company, and *Engineering News-Record* published by McGraw-Hill. As a service to its readers, *Engineering News-Record* compiles and publishes an extensive amount of data on material prices and construction labor costs. A small amount of this data is then used to calculate two monthly index figures, the Construction Cost Index and the Building Cost Index. Each index is widely used throughout the U.S. construction industry as a benchmark for measuring inflation. These indexes can also be used to contemporize and correlate aged cost data with the base year of the estimate.

Other sources for cost guides include specialized trade associations such as the American Concrete Pipe Association and the Iron and Steel Institute, among numerous others. All of these guides are only that; the unit prices should never be used blindly, since conditions vary from region to region and, in fact, from project area to project area within the same jurisdiction.

ENGINEERING ECONOMY

Occasionally, the land development engineer is asked to assist the client in evaluating a series of alternatives (value engineering), which may involve a type of decision making called *engineering economic analysis*. The intent of presenting the following information is not to provide a complete discourse on the subject, but to summarize the formulas used in textbooks on the subject. The reader is directed to any of the engineering economy texts listed in the bibliography for a full explanation of the subject, as well as the necessary tables to apply the principles involved.

Interest Formulas

While texts on engineering economics use different symbols, the following are the ones most commonly used and are taken from a well-respected text on the subject (Grant, 1990).

Symbols

i = interest rate per interest period.
n = number of interest periods.
P = present sum of money.
F = sum of money at the end of n periods. It is equivalent to P with interest i added.
A = end of period payment or receipt in a uniform series continuing for n periods.

Formulas. The following information is provided to enable one to utilize the interest tables quickly when calculating the information needed to analyze engineering economy problems.

			Company A		Company B		Company C		Company D		Company E	
DESCRIPTION	QTY	MEAS.	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL	UNIT PRICE	TOTAL
Clearing & Grubbing	1	LS	2,000.00	2,000.00	2,500.00	2,500.00	3,280.00	3,280.00	2,000.00	2,000.00	1,000.00	1,000.00
Construction Stakeout	1	LS	2,500.00	2,500.00	1,500.00	1,500.00	1,000.00	1,000.00	2,000.00	2,000.00	1,500.00	1,500.00
Maintenance of Traffic	1	LS	2,500.00	2,500.00	5,000.00	5,000.00	3,000.00	3,000.00	4,000.00	4,000.00	5,000.00	5,000.00
Temp. Concrete Barrier for M.O.T.	140	LF	10.00	1,400.00	15.00	2,100.00	12.00	1,680.00	20.00	2,800.00	40.00	5,600.00
Traffic Drums	50	EA	25.00	1,200.00	85.00	4,250.00	55.00	2,750.00	30.00	1,500.00	50.00	2,500.00
Temp. Pavement Tape Marking	1,020	LF	1.40	1,428.00	1.60	1,632.00	0.60	612.00	1.50	1,530.00	2.00	2,040.00
Class 1 & 2 Excavation	638	CY	15.00	9,570.00	18.00	11,484.00	20.00	12,760.00	22.00	14,036.00	39.00	24,882.00
Select Borrow	100	CY	15.00	1,500.00	5.00	500.00	5.00	500.00	22.00	2,200.00	10.00	1,000.00
Silt Fence for Sediment Control	600	LF	1.50	900.00	1.50	900.00	0.01	6.00	1.00	600.00	2.00	1,200.00
Test Pit Excavation Cont.	40	CY	50.00	2,000.00	10.00	400.00	35.00	1,400.00	50.00	2,000.00	5.00	200.00
Stabilized Construction Entrance	50	SY	25.00	1,250.00	11.00	550.00	11.00	550.00	15.00	750.00	10.00	500.00
Strawbales / Sandbags (Sed. Control)	50	EA	5.00	250.00	5.00	250.00	5.00	250.00	1.00	50.00	3.50	175.00
Temp. Curb Inlet Protection	3	EA	200.00	600.00	200.00	600.00	125.00	375.00	150.00	450.00	75.00	225.00
Select Borrow for Trench Bckfill	25	CY	40.00	1,000.00	5.00	125.00	22.00	550.00	24.00	600.00	10.00	250.00
15" RCP Class V	87	LF	35.00	3,045.00	83.00	7,221.00	60.00	5,220.00	35.00	3,045.00	60.00	5,220.00
18" RCP Class V	14	LF	50.00	700.00	87.00	1,218.00	55.00	770.00	60.00	840.00	60.00	840.00
Bituminous Concrete Base	162	TN	45.00	7,290.00	45.00	7,290.00	50.00	8,100.00	70.00	11,340.00	50.00	8,100.00
Bituminous Concrete Surface	126	TN	47.00	5,922.00	50.00	6,300.00	55.00	6,930.00	70.00	8,820.00	60.00	7,560.00
Aggregate Subbase for M.O.T.	50	TN	50.00	2,500.00	15.00	750.00	15.00	750.00	10.00	500.00	10.00	500.00
Calcium Chloride for M.O.T.	2	TN	250.00	500.00	300.00	600.00	350.00	700.00	50.00	100.00	200.00	400.00
Bitumin. Conc. (Cold Mix) M.O.T.	25	TN	50.00	1,250.00	45.00	1,125.00	50.00	1,250.00	50.00	1,250.00	30.00	750.00
Pavement Profiling (Milling)	552	SY/I	3.00	1,656.00	4.00	2,208.00	5.00	2,760.00	5.00	2,760.00	4.50	2,484.00
Poly. Paving Fabric for Bit. Conc.	120	SY	10.00	1,200.00	1.75	210.00	2.00	240.00	3.00	360.00	2.00	240.00
5" Conc. Sidewalk & S/W Ramps	185	SY	27.00	4,995.00	24.00	4,440.00	27.00	4,995.00	20.00	3,700.00	22.50	4,162.50
		TOTALS		57156		63153		60428		67231		76328.5

FIGURE 29.3 Bid tabulation example.

ARLINGTON COUNTY
DEPARTMENT OF PUBLIC WORKS
PUBLIC IMPROVEMENT PERFORMANCE BOND ESTIMATE

SUBDIVISION/SITE PLAN NAME ______________________

ADDRESS/LOCATION ______________________

SUBMITTED BY ______________________ DATE ______________

Item	Quan.	Unit	Unit Price	Cost	Item	Quan.	Unit	Unit Price	Cost
Excavation including Clearing & Grubbing		Cu. Yds.	$23.75		Trees on Public R/W		Each	$330.00	
Conc. Curb & Gutter		Lin. Ft.	$15.00		Tree Grates		Each	$700.00	
Conc. Drive Entrance		Sq. Yd.	$35.00		Street Lights Type - Thoroughfare		Each	$6,000.00	
4" Conc. Sidewalk		Sq. Yd.	$25.50		Street Lights Type - Colonial		Each	$4,500.00	
Brick Paver Sidewalkon Aggregate Base		Sq. Yd.	$46.25		Restoration: Sod, etc.		Lump Sum		
Brick Paver Sidewalk on 4" Conc. Base		Sq. Yd.	$60.50		Erosion/Silt Controls		Lin. Ft.	$6.00	
Brick Paver Sidewalkon 6" Conc. Base		Sq. Yd.	$70.00		CB-2 Catch Basin		Each	$2,275.00	
Brick Paver Crosswalkon 6" Conc. Base		Sq. Yd.	$140.00		Catch Basin (misc.)		Each		
Wheel Chair Ramps		Each	$315.00		CB-2 Top Remove & Replace		Each	$1,225.00	
Bike Trail 4" Asphalt with 6" Comp. Subbase		Sq. Yd.	$17.00		MH-1 Storm Sewer Manhole		Each	$2,525.00	
Subbase - C.B.R. 30		Cu. Yd.	$29.00		MH-2 Storm Sewer Manhole		Each	$3,300.00	
B-3 Bituminous Concrete Base		Ton	$57.00		Storm Sewer Manhole (misc)		Each		
S-5 Bituminous Concrete Top		Ton	$60.00		MH-1 Top Remove and Replace		Each	$1,000.00	
Remove Conc. Curb & Gutter		Lin. Ft.	$7.00		MH-2 Top Remove & Replace		Each	$1,250.00	
Remove Conc. Sidewalk		Sq. Yd.	$5.00		15" R.P.C. Cl. III Pipe		Lin. Ft.	$44.00	
Remove Conc. Drive Entrance		Sq. Yd.	$6.00		18" R.P.C. Cl. III Pipe		Lin. Ft.	$48.00	
Conc. Retaining Wall		Cu. Ft.	$19.50		24" R.P.C. Cl. III Pipe		Lin. Ft.	$63.00	
Stone Retaining Wall		Cu. Ft.	$12.50		_____ R.P.C. Cl. III Pipe		Lin. Ft.		
Storm Water Detention System		Lump Sum							

FIGURE 29.4 Bid tabulation example.

Item	Quan.	Unit	Unit Price	Cost	Item	Quan.	Unit	Unit Price	Cost
4" Water Line D.I.P. Class 52		Lin Ft.	$45.00		8" San Sewer Pipe Less than 10' Deep		Lin Ft.	$55.00	
6" Water Line D.I.P. Class 52		Lin. Ft.	$51.00		8" San Sewer Pipe Greater than 10' Deep		Lin Ft.	$160.00	
8" Water Line D.I.P. Class 52		Lin. Ft.	$55.00		15" San. Sewer Pipe Less than 10' Deep		Lin. Ft.	$80.00	
12" Water Line D.I.P. Class 52		Lin. Ft.	$64.00		15" San. Sewer Greater than 10' Deep		Lin. Ft.	$210.00	
16" Water Line D.I.P. Class 52		Lin. Ft.	$78.00		4' I.D. San. Sewer M.H.		Vert. Ft.	$300.00	
6x6 Tapping Sleeve and Valve		Each	$2,200.00		5' I.D. San. Sewer M.H.		Each	$350.00	
8x8 Tapping Sleeve and Valve		Each	$3,150.00		San M.H. Adj. to Grade		Each	$350.00	
12x12 Tapping Sleeve and Valve		Each	$4,150.00		Tunneling 24" Carrier Pipe		Lin. Ft.	$750.00	
16x12 Tapping Sleeve and Valve		Each	$4,068.00		Traffic Signalization*		Lump Sum		
24x12 Tapping Sleeve and Valve		Each	$8,050.00						
2' Blow Off Valve		Each	$1,500.00						
Fire Hydrant		Each	$1,325.00						
Fire Hydrant (relocate)		Each	$1,000.00						

*Contact the Department of Public Works Traffic Signal Engineer on 358-3575 for cost if required by this subdivision/site plan.

ADDITIONAL ITEMS

SUB-TOTAL ___________

20% ADMINISTRATIVE, ENGINEERING & MISC. FEE ___________

TOTAL QUOTE ___________

REVIEWED AMOUNT APPROVED BY ARLINGTON COUNTY (FOR COUNTY USE ONLY ___________

BY___________________ DATE___________________

FIGURE 29.4 *(Continued)*

$$F = P(1+i)^n \tag{29.5}$$

$$P = F\left[\frac{1}{(1+i)^n}\right] \tag{29.6}$$

$$A = F\left[\frac{i}{(1+i)^n - 1}\right] \tag{29.7}$$

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \tag{29.8}$$

$$F = A\left[\frac{(1+i)^n - 1}{i}\right] \tag{29.9}$$

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] \tag{29.10}$$

The factors, which vary by interest rate and number of periods, are found in most engineering economic analysis texts. They are usually written as (Factor, *I, n*). For example, the uniform series present-worth factor at $i = 7$ and for $n = 10$ would be written as (PWF, *i, n*) or (PWF, 7%, 10), and is equal to 0.5083. This factor can be determined by looking at a table or by substituting the values into Equation 29.5. When solving complex engineering economics problems, it is a good idea to draw a cash flow diagram. A simple problem illustrates.

EXAMPLE 3

How much does one have to invest today to be able to achieve draws of \$2000 at the end of each year for five years, assuming interest is at 7 percent per year?

First, prepare a cash flow diagram (Figure 29.5). To find *P* given *A* at $n = 5$ and $i = 7$,

$$P = A\,(\text{Present Worth Factor}) \tag{29.11}$$

$$= A\,(\text{PWF}, 7, 5)$$

$$= 2000\,(4.100)$$

$$P = \$8200$$

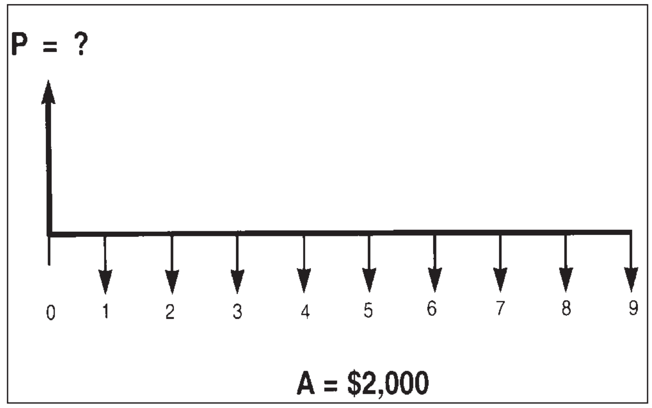

FIGURE 29.5 Cash flow diagram for example 3.

The next problem is included as an example of alternative analyses that are commonly encountered in land development engineering. It uses the principles of engineering economics as described previously.

EXAMPLE 4

You are the engineer for a major landowner and developer. Your client needs to construct a storm drainage facility that extends under a state roadway. Your client has requested that you compare two alternative storm drainage pipe systems and has provided you with two bids from his contractor. Alternative A has a service life of 50 years and a bid cost of \$1,575,800. Alternative B has a service life of 25 years with a construction bid of \$1,275,000. Since your client will be the owner over the life of the facility, he wants to be sure he selects the least-cost alternative over the long term.

You, as the engineer, investigate and find that the state highway department requires a service life of 50 years, meaning that Alternative B could require replacement once during the service life of the project. You are aware that inflation is at 4 percent and interest rates are at 7 percent.

ASSUMPTIONS/FACTS	ALTERNATIVE A	ALTERNATIVE B
Bid cost (*P*)	\$1,575,800	\$1,275,000
Life (*n*)	50 years	25 years
Interest (*i*)	7%	7%
Inflation	4%	4%

Your client has asked you to compare the life cost for each alternative on an annual cost basis.

For alternative A, using the economic analysis equation for annual equivalent cost (see Engineering Economics Tables):

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] = P\,(\text{CRF}, 7\%, 50\text{ yrs}) \tag{29.12}$$

$$= 1{,}575{,}800\,(0.07246)$$

$$A = \text{Annual Cost}_{\text{ALT A}} = \$114{,}182$$

In Alternative B, the pipe is assumed to need replacement in 25 years, since the service life is 25 years. Here you assume that, at an inflation rate of 4 percent per year, the cost to replace in 25 years is:

$$S_{25} = P(1+i)^n = P\,(\text{CAF}, 4\%, 25\text{ yrs}) \tag{29.13}$$

$$= 1{,}275{,}000\,(2.6658)$$

$$S_{25} = \$3{,}398{,}895$$

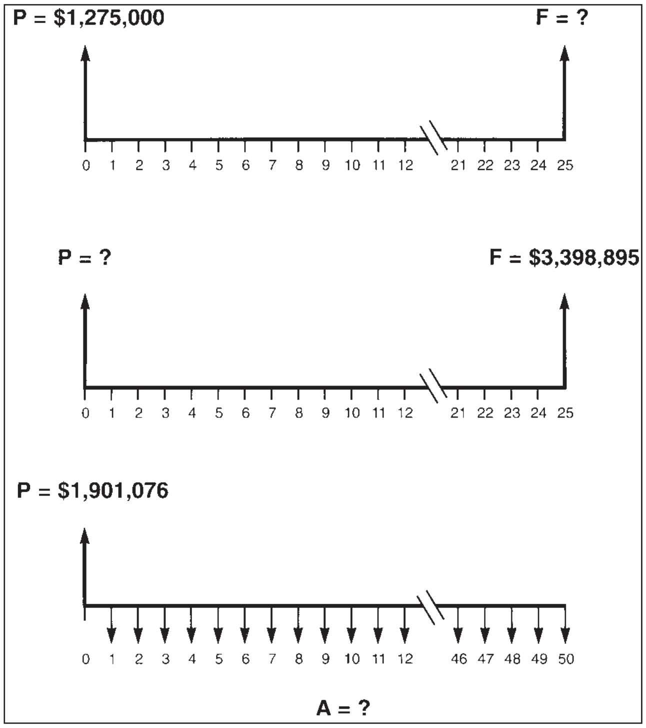

Figure 29.6 Cash flow diagram for Example 4.

Next, find the present value of \$3,398,895 using i = 4%.

$$P = S\left[\frac{1}{(1+i)^n}\right] = S\,(\text{PWF, 7\%, 25 yrs})$$

$$= 3{,}398{,}895\ (0.1842) \qquad (29.14)$$

$$= \$626{,}076$$

Adding this value to the first installation cost, you find \$1,275,000 + \$626,076 = \$1,901,076 for the total present value of Alternative B. Since you have been asked to compare the alternatives on an annual cost basis, you calculate:

$$A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]$$

$$= P\,(\text{CRF, 7, 50 yrs}) \qquad (29.15)$$

$$= 1{,}901{,}076\ (0.07246)$$

$$A_{\text{ALT B}} = \$137{,}752$$

Figure 29.6 is a diagram that shows Alternative B cash flows for each step.

Note that the whole computation process of finding the annual cost could have been done in one step:

$$A = (P\,(\text{CAF, 4\%, 25})(\text{PWF, 7\%, 25}) \times (\text{CRF, 7\%, 50}) + P)\ (\text{CRF, 7\%, 50}) \qquad (29.16)$$

Based on the preceding assumptions on an annual equivalent cost basis, Alternative A is \$114,182 per year and Alternative B is \$137,752 per year. In this example, no cost of removing the pipe at 25 years is included. You advise your client that Alternative A, with the higher current bid cost, is the least-cost solution over the life of the facility (50 years). You prepare a report to your client documenting your analysis and assumptions and put a copy in the project files.

SUMMARY

Accurate, all-inclusive, and timely cost estimates are indispensable mechanisms in all stages of a development project, large or small. All assumptions and quotes from suppliers/vendors/manufacturers/specialty contractors must be presented in clear and dated notes. The size of the project determines the potential complexity and multistage levels of cost estimating required.

While quantity takeoff for the project requires a thorough understanding of the engineering drawings and specifications, it also requires significant engineering judgment, diligence, and research to procure accurate, current-unit-cost data that is reflective of the size, type, location, and timing of the project as well as the current state of the economy and financial facets of the project.

REFERENCES

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PART VI

PLAN SUBMISSION AND PERMITTING

STEP 6: PLAN SUBMISSION AND PERMITTING

Once the final construction documents are prepared, the land development consultant can pursue the necessary approvals and permits required to actually break ground at the site. For many clients, an approved rezoning (entitlement) or successful subdivision is the first critical path element: this is the determining factor in terms of moving forward with the development program and detailed design efforts. Subsequent to entitlement, the next (second) critical path element is often an approved site plan (or local equivalent) and building permit, as these are both required to commence construction. Given this front-end emphasis on land development services, the value of a qualified, local land development consultant is evident.

Knowledge of the local review and approval process, refined negotiation skills, and a thorough understanding of project schedules and permit time frames are important in terms of procuring timely approvals. Depending on the jurisdiction, several iterations of plan submission and review could be required depending on the plan size, complexity, and quality of the final design: consultants must be prepared to defend their work technically yet be flexible enough to accommodate modifications requested by review staff. In other words, land development consultants must pick their fights wisely in order to successfully balance client project schedules and jurisdictional working relationships.

This phase of the design process is particularly important as it is the primary QA/QC (quality assurance/quality control) opportunity for the land development consultant, clients, and review staff. Well-defined QA/QC checks prior to or as a component of formal submissions facilitate plan consistency and the ability of jurisdictions to process plans efficiently as well as protecting the professional integrity of the consultants and reviewers who sign, seal, or otherwise authorize the plans. Further, the review and approval process is the official documentation of land use or built environment decisions. Plans, plats, and other documents are legal instruments that are recorded and available to the public in perpetuity. Thus, the importance of clear, accurate, constructible plans cannot be emphasized enough.

Projects pursuing a third-party review such as green building certification need to submit all design documentation at this stage of the process. Submissions made at this phase allow for early review and revisions that, if necessary, can be incorporated during the construction process with, ideally, little impact to overall costs and schedule projections. Depending on the certification sought, additional submissions may be required during or after construction in order to verify design implementation. Documentation efforts should continue through construction to ensure that certification goals established at the start of the project are met.

CHAPTER 30

PLAN SUBMISSION, REVIEW, AND APPROVAL PROCESS

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Updated/Revised: Terrance Ryan, PhD, PE

INTRODUCTION

Some development projects can take place without the necessity for rezoning. However, more often than not, a rezoning process precedes the detailed design for construction. Approval of a rezoning application is insufficient to initiate construction. Detailed design and structural analyses are rarely incorporated to a sufficient degree in the rezoning process. The development team can encounter numerous pitfalls in attempting to translate an approved zoning plan into a subdivision or site plan submittal.

The engineering analysis performed for a subdivision or site plan, as part of the construction document preparation, often suggests that the assumptions used in the rezoning submittal were insufficient for final design, sometimes are imprecise, and in some cases are incorrect. This is because of the differing level of detail each type of approval requires. Because of the risk and expense involved in achieving this level of accuracy with the more speculative legislative rezoning application, many land developers are reluctant to add the costs associated with greater exactness. Yet some jurisdictions require legislative approval of revisions to the previously approved rezoning and/or preliminary development plans when changes are made as a result of subsequent, more detailed engineering. As with so many aspects of development review, the hesitancy to allow administrative corrections and approvals stems from fear of abuses by owners/developers and claims of unequal treatment from the public and other developers.

The rezoning process is not intended to be the approval process to begin construction. The rezoning process is intended merely to designate the allowed use of the land under the circumstances portrayed in the plans and other documents submitted in support of that process (hereafter, collectively called *plans*). It should be obvious that construction could not take place using the plans developed for the rezoning process. Much more detailed plans are necessary. These detailed engineering plans must also be approved by public agencies prior to the issuance of a permit, as the plans must contain instructions and requirements to be adhered to and met by the contractor to ensure protection of the public.

The rationale for plan approvals cannot be better stated than as found in older publications regarding this authority. The plan approvals in regard to the associated codes and ordinances "are essential to meet the needs of the community in the fields of public health, safety, and economic and social well-being. Provision of this public protection rests upon the police power of the government. Police powers are reflected in the enactment of master plans, zoning codes, building and building equipment codes, housing and sanitation codes and other regulatory ordinances. Good codes, well-administered, provide the only sound means for a balanced program to insure the orderly development of a city, the prevention of slums and blight, and the safe-guarding of life, health, and property" (International City Manager's Association, 1957).

Each jurisdiction has administrative requirements and procedures that govern the various plan submittals. Failure to follow these requirements can at best result in a delay in the plan's approval. It is possible for the plan to be disapproved even though it has been designed in accordance with accepted standards if it fails to adhere to the administrative requirements dealing with the particular way a jurisdiction desires to see the construction information. Most jurisdictions welcome a preapplication meeting with staff so that the types of plans needed and the application process is understood.

The land development process is often lengthy and arduous. This is especially true in developing urban areas. Some minor development plans take as long as or longer to follow the review process than it has taken to develop the design. The time schedule for the review process needs to be taken into account when planning a land development project. This prevents costly surprises and provides a realistic time frame in which the client can anticipate approvals and the ability to procure or "pull" required permits.

Previous chapters have discussed, in detail, comprehensive planning, zoning, subdivisions, and a myriad of other elements of the development process. This chapter focuses on (1) preparation of the plan submission and (2) the plan review and approval process. It is at this point in the process that the developer is preparing to initiate construction and welcomes this critical element. Topics covered are typical submissions, how submissions are sequenced within the approval process, who reviews submissions and why, and common processing considerations.

PREPARING THE PLAN SUBMISSION

Guided by the jurisdiction's administrative regulations, the plan submittals are the developer's actual representation of the proposed development. Consisting of drawings and other design information, the plan sets or submissions show (with increasing detail) the arrangement of property lines, lots, and other features that will occupy the site. Plans and plats identify the public and private facilities to serve the intended uses as well as provide information on how those facilities will be constructed, from grading of the property through connection of utilities to pedestrian and vehicle access arrangements.

Before expending significant time and money for the preparation of final layouts and construction plans, the developer wants assurances that plans will be approved. The various plans submitted during the process incorporate a series of checkpoints with the reviewing agencies. Many communities have established three checkpoints within their submission and review process: sketch plan or preapplication, preliminary plan, and final plan (see Figure 30.1). These checkpoints generally correspond to the land development design steps—conceptual, schematic, and final—and enable the development team to gauge whether its interpretations of local policies, regulations, and standards match those of local government authorities. Otherwise, extensive redesign would be needed. For example, redesign would be needed if the lot layout did not fully comply with the requirements of the zoning ordinance, or the street and utility system did not properly consider planned or existing networks.

Reports, studies, specialty plans, and other miscellaneous documents (often reviewed and approved separately from the plan they support) are needed in a certain sequence or concurrent with the appropriate design plan submission. The sequencing is dependent on the type of plan being submitted and the requirements of the individual jurisdiction.

Typical Plan Submissions

Not all plan types are subject to the same administrative requirements. Examples of some common plan submissions are listed in Table 30.1. The number of copies shown for each plan submission should not be taken as absolute, but merely typical, since many jurisdictions require fewer copies. The number of copies requested is often dictated in the jurisdiction's administrative review requirements and codes or by ordinance and is normally based on the number of review agencies and the method of transmitting and returning review comments. It is more efficient for concurrent review to be taking place on a set of plans rather than one or two sets being reviewed by agencies in sequence. Depending on the plan type and complexity, it is not unusual for 15 or more copies of a particular plan to be required for submittal.

Preliminary Plan

Where the sketch plan or concept plan was presented to discuss ideas and identify problems, the preliminary plan could be considered as the first formal submission. In some jurisdictions, the two plans can be the same document. The only difference is that the sketch plan isn't reviewed and approved and the preliminary plan becomes the official document. The preliminary plan is perhaps the most important, as it represents the parameters by which the site will be engineered and construction plans prepared. Many developers/owners refer to this as the *entitlement* document, and it is typically the first critical path element for most land development projects. In addition to the plan itself, many preliminary plans have affiliated development conditions or proffers that further clarify the proposed development program and outline the various exactions the developer is obligated to fulfill. This plan and its affiliated documents will be reviewed by the agencies for compliance with all applicable codes and ordinances as well as compatibility with surrounding areas. Whatever is approved as part of the preliminary plan must be adhered to throughout the entire life of the project. To change what is shown on the approved preliminary plan may require starting the time-consuming process from the beginning, which may be very costly to the developer. The preliminary plan does not give the developer any right or privilege to begin construction operations on the site. It is merely a method of communication by which the developer shows the local government and other regulating agencies, in more accurate detail than a sketch plan, how the proposed development will be accomplished. It is not uncommon for the preliminary plan to accompany or even form a component part of the rezoning application.

The preliminary plan is for the entire project; it shows relationships and ties to each section or phase of construction for large sites. Regulations often specify the minimum area that can be sectioned from a larger project for inde-

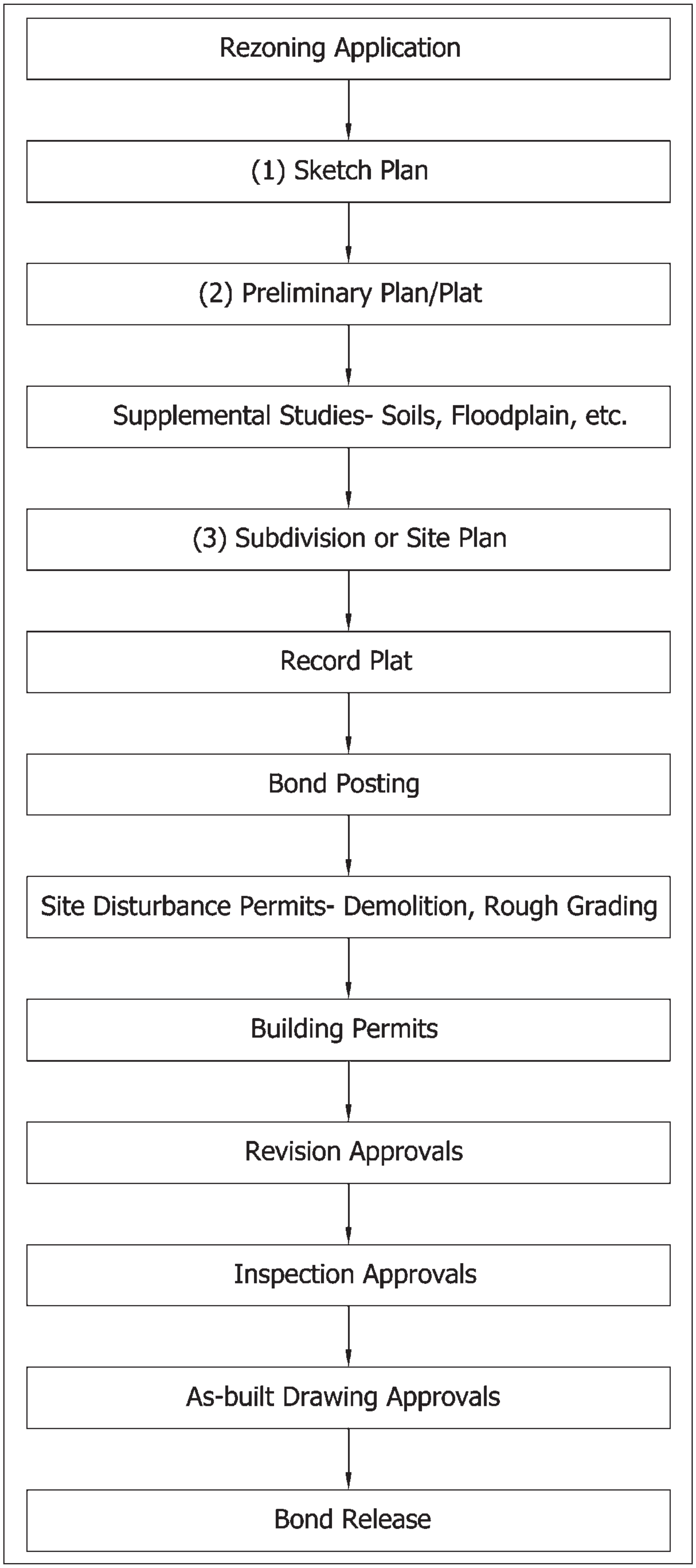

Figure 30.1 Typical sequence of plan submissions.

TABLE 30.1 Number of Submittal Copies Needed for Various Plan Types

PLAN TYPE	NO. OF COPIES
Drainage study	2
Final record plat	5 paper, 1 Mylar
Final record plat redate	5 paper, 1 Mylar
Floodplain study	4
Preliminary plat	22
Preliminary plat redate	22
Preliminary plat revision	22
Public improvement plan	13
Rough grading plan	8
Site plan	20
Site plan revision	5 + 2 per outside agency
Soils report	2
Subdivision plan	16
Subdivision plan revision	16
Waiver condition and copy of plan	2

pendent preliminary review. In addition, each section, along with previously approved sections is usually required to form a self-sustaining project, capable of standing alone in terms of regulatory compliance. That is, in the event that the developer delays or abandons future sections, those previously approved satisfy ordinance and functional requirements. The coordinating agency often maintains, or in some cases requires the applicant to maintain, an accounting of critical elements of the project that are intended to support its population as the project progresses. Regardless of regulation, the sections should be selected to ensure that access and infrastructure can be constructed without exceedingly long connections to existing facilities.

The preliminary plan is drawn to a scale sufficient to show the necessary detail. A preliminary plan typically includes the following information:

- Soils, geology, and field-verified topography
- Field-surveyed site boundary
- Adjacent property owners, zoning, and use
- The proposed lot layout of the project showing area, dimensions, and other property line information
- Information regarding height, bulk, and area requirements of any existing and proposed structures
- Street layout including off-site improvements, centerline alignment, profiles, typical cross sections, turn lanes, intersections and entrances, sidewalks and trails, and traffic control signs and devices
- Proposed street names
- Location of existing utilities and easements
- Location of proposed public utilities, including sizing and alignment of sewer, water, and fire hydrants and conduit runs
- Sizing and location of proposed major drainage systems, including outfall and drainage area analysis, accurate floodplain delineation, pipe sizing, and existing and proposed stormwater management facilities
- Proposed easements, both temporary and permanent, for access, utilities, construction, and maintenance
- Information regarding buffers, landscaping, clearing limits, and impact mitigation
- Septic drainfield and perc information, and well sites for projects using package water treatment systems and/or individual wells

Final Plan

As the details of the data are refined, discussions about the project can occur with more certainty and the project evolves one step further from preliminary plans in schematic design to final design efforts. The final design stage is represented by the construction drawings and specifications created by the engineers on the design team. In many jurisdictions, the approved construction documents are part of the final subdivision or site plan; in others, the construction documents are a separate phase of the development process, not associated with the final plan and plats. The final plan is commonly referred to as the *subdivision plan* or *site plan,* depending on the jurisdiction, the proposed use, and other procedural factors.

The developer must have approved construction plans and specifications in order to obtain certain building permits, without which construction cannot begin. The construction or final plan set details the way in which the project is to be built. The final plans generally include:

- Detailed site plan or geometric layout of proposed facilities in substantial compliance with the previously approved preliminary plan
- Detailed plan and profile of the roads including traffic control, signage, and pavement marking plans

- Detailed plan and profile of water and sanitary lines
- Detailed plan and profile of storm drainage system
- Detailed plan and profile of conduit systems
- Grading plan
- Erosion and sediment control plans
- Enumeration of the specifications to be used for construction
- Stormwater management plans, details, and profiles
- Fire lane marking plan
- Detailed landscaping plans including a plant schedule and installation details
- Construction details for nonstandard or modified components
- Detailed specialty designs for such things as on-site water supply systems, on-site sanitary treatment facilities, and so on.
- Documentation information referencing relevant prior approvals for such items as preliminary plans, waivers, variances, reports (i.e., geotechnical and traffic), and studies (i.e., tree conservation, historic/archaeological preservation, or wetland impact studies)

The size and complexity of the project, along with the scale needed to sufficiently show accurate detail, can result in a plan set of considerable size. Care must be taken to clearly identify the proper relationship between various drawings. The organization of these plans depends on the particular ordinance or policy, the land design team, and the project itself—for general plan set organizational recommendations, see the section entitled "Plan Set Sequence and Format."

Record Plat. In addition to the construction drawings, the final plan submittal includes the final record plat. This plat establishes a public record for the project by which property will be sold or leased and identifies the final location of property lines and easements for public utilities. The record plat contains extensive notes with respect to ownership, dedication, completion of public improvements, and restrictions. These affect the chain of title, use, and enjoyment of the property and serve to notify future owners of their rights and obligations. Typical information required to be shown on the record plat includes:

- Project or subdivision name and section
- Parcel boundaries, including bearings and distances, as well as the legal description
- Adjoining property lines, including ownership information
- Street right-of-way boundaries, including surveyed bearings and distances
- Street names both existing and proposed
- Lot lines, including surveyed bearings and distances, lot and block numbers, lot addresses, and building restriction lines
- Building footprint for certain types of uses
- Existing easements and easements created as a part of the development, including purpose and deed references
- Location of survey monuments and markers
- Conservation and other building-restricted areas, such as septic drainfields
- Ownership declarations and dedications
- Covenants and restrictions, including reference to separate documents in the jurisdiction's public land records
- Approval blocks for signature(s) of authorized government officials
- Original seal and signature from the preparing engineer or surveyor

As-Builts or Record Drawings. Although not identified as a primary checkpoint in the development review process, it is important to note that most jurisdictions require the development team to produce as-built drawings (officially known as *record drawings*) upon completing construction. These drawings are usually modifications of the project's construction drawings, intended to reflect field changes by construction contractors. These drawings serve two important purposes. First and foremost, they present government agencies with the final opportunity to verify that construction complies with local regulations and standards. This is necessary to ensure that systems will function properly and not cause unanticipated impacts to the larger community. Second, the plans facilitate future maintenance and repair, particularly for underground utilities whose location, sizing, and method of construction are otherwise hidden from view. For more specific information on as-built surveys, see Chapter 34.

Plan Set Sequence and Format

Just as each jurisdiction has its own list of required submittals, each also typically has requirements as to what constitutes a set of plans and the format of the plan set. In general, construction-related information is assembled in logical order toward the front of the plan set, and the non-construction-related data is placed at the end of the plan set. Specific plan sheets in a typical set of plans submitted for approval fall into five categories:

1. Cover sheet
2. General information
3. Specific construction sheets

4. Additional construction sheets
5. Documentation information

(Engineers and Surveyors Institute, 1990.)

Cover Sheet. The cover sheet typically contains a location map, an index of all sheets, plan identification (title and/or tracking number assigned by the jurisdiction), submitting engineer data, information considered pertinent to someone seeing the plan for the first time, and other general information. Some jurisdictions will require an *original* engineer's seal and signature on the plan cover sheet. Original seals from other licensed/certified professionals on the design team such as the surveyor, geotechnical engineer, landscape architect, and/or arborist may also be required, depending on the jurisdiction, scope of the project, and plan type.

General Information Sheets. These sheets contain all general notes not shown on the cover sheet. Typically, general information sheets contain the plan legend, typical sections, construction details, and modified designs. Information sheets also reference the construction specifications to be followed. Tabulations may also be included for such items as parking, loading spaces, and building data.

Specific Construction Sheets. Specific construction sheets consist of plan and profiles of the infrastructure (such as streets, utilities, sidewalks, and trails) as well as grading details and grading plans. It also would include the plan and profiles of storm water management facilities and overall plans for such items as water meters, fire hydrants, streetlights, street trees, signage, and similar types of construction details. All public facilities must be documented in the appropriate format.

Additional Construction Sheets. Additional construction sheets would contain miscellaneous construction details such as utility and drainage profiles not previously shown (typically private and requiring special design consideration), remaining profiles such as driveways, and special design items. Here also would be included the landscaping plans, erosion and sediment (E&S) control plans, fire lane marking plans, street signing and marking plans, and geotechnical information. The landscaping sheets would include the plant list and landscape construction details. The erosion and sediment sheets would include the narrative and notes, sequence of construction, computations with sediment trap sizes and siltation or drainage divides, and any details necessary for installation. The geotechnical plan sheets would show geotechnical notes, foundation drains, or other geotechnical construction details and recommendations. A full geotechnical report is sometimes necessary and is often included in its entirety with the plan submission.

Nonconstruction Data Sheets. Plans and documents needed for plan approval include the detailed calculations and methodology used to design the construction plans. This would include drainage area diagrams and stormwater routing calculations used to size the stormwater drainage and management systems, as well as floodplain studies. Outfall narratives, ditch cross-section computations, and storm inlet computations would also be included. Fire flow calculations would need to be provided to the fire and water authorities. Plan approval documents would also include sight distance calculations at intersections and critical driveways. Soils reports and other geotechnical information are also provided in plan form as well as in reports, if not included in previous sheets.

In some jurisdictions, verification that appropriate public notices have been sent and permits from other agencies obtained is also needed. Other correspondence and supporting nonconstruction data sheets would include such information as construction waiver requests/approvals, record plats, easement plats, and supporting documents such as preliminary plans and development plans already approved by the jurisdiction, as well as any proffer compliance or development condition narratives that may be warranted.

Plan Set Format. Most jurisdictions also have aesthetic standards for plan sets including detailed guidelines for such items as sheet size, drawing scales, indexing conventions, lettering size, and, occasionally, line-type presentation. The engineer needs to determine the requirements for each sheet of each submission in order to plan and develop the sheet layouts and plan sets accordingly. Understanding the jurisdictional administrative requirements is of paramount importance in terms of streamlining the actual drawing production process.

In many cases, the same drawing needs to appear at several different scales throughout the course of a plan set; computer-aided design and drafting (CADD) has made it possible for designers to quickly change and adjust the scale of any drawing. Further, most CADD applications have built-in operations that assist users in setting up sheets. These operations allow users to quickly assemble sheets and plan sets with a consistent format, store them for rapid reproduction, and archive them effectively for lasting electronic records of plan prints/submissions. Like any of the CADD applications discussed in this text, the final product of this tool is entirely dependent on detailed user input that provides information accurate enough to create the desired result.

PLAN REVIEW AND APPROVAL PROCESS

Figure 30.2 provides a comprehensive view of how the flow of a project from conception to occupancy occurs. In any specific jurisdiction there will be variations; however, this chart provides an accurate overview.

The plans and accompanying documents are prepared, submitted, and reviewed in a predetermined sequence of increasing accuracy and detail. This staging of analysis and design is important. Some jurisdictions require planning commission review and approval of preliminary plans. Most but not all jurisdictions consider construction plan approvals as an administrative act of the staff, without involvement of the legislative body or the public. Lately, however, notification of stakeholders has been integrated into the approval process. In addition, even the most prescriptive or-

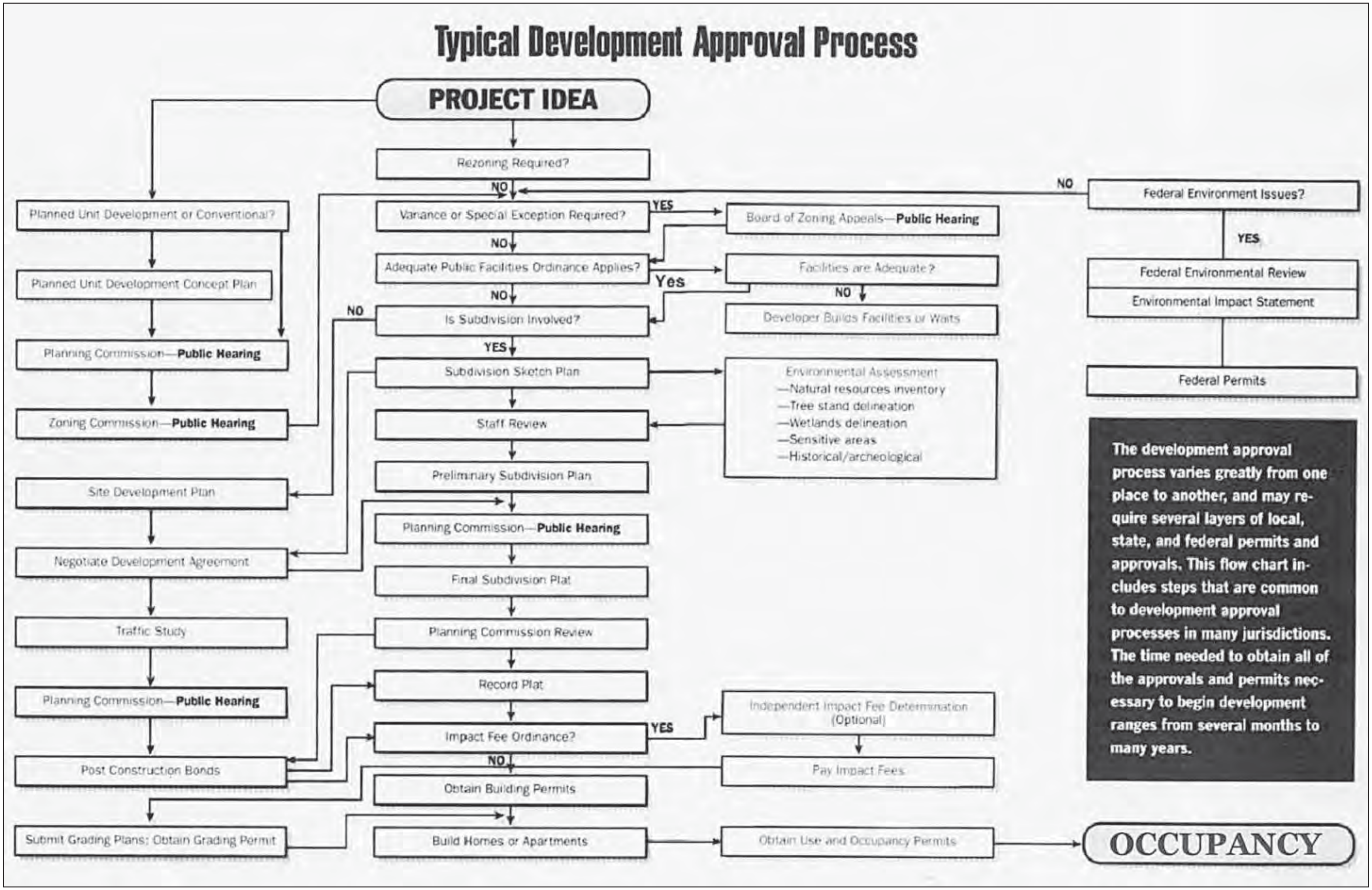

FIGURE 30.2 Generic flowchart for land development project. (National Association of Home Builders)

dinances allow and necessitate considerable judgment by design professionals concerning on-site layout and connection of off-site facilities.

One of the most common unknowns for the submitting engineer is what agency needs which plans and when are they needed. New and revised regulations and new procedures often change the agencies needing to review and approve development plans. Engineers often do not submit enough plans to any one jurisdiction to develop a thorough knowledge of the administrative procedures. For this reason, it is beneficial to review the written procedures as well as to seek the advice of others who are knowledgeable about the process and practice prior to submitting a plan for review and approval. In some jurisdictions, these procedures are typically included in a subdivision and site plan ordinance or a public facilities and standards manual. As previously indicated, many jurisdictions welcome a presubmittal conference.

Electronic Submission, Review, and Approval (ESRA) of Plans

The application of technology to enhance the complex communication process of plan submission, review, and approval is promising. A working definition of ESRA is *the application of computer and Internet technology to the submission, review, and approval of plans in such fashion that any piece of the plan document set is never converted from electronic (soft copy) to paper (hard copy) and back during the process.*

On first consideration, since most plan documents involve the use computer-aided design (CAD), computer-aided engineering (CAE), geographic information systems (GIS), spreadsheet models using such programs as Microsoft Excel, and so on, it seems that extending technology to the process would be almost trivial. After many years of attempts to apply technology to the process, the goal of a complete, integrated approach to ESRA to save resources remains elusive. The impediments to the goal are now more human-driven than technology-driven due to the complexity of the process.

Submission Phase: A frequent example of electronic-to-paper conversion and back is when a plan set is accepted at a jurisdiction for review: the applicant prepares the plans electronically (soft-copy form), prints at least one set for submission or log-in (thus converting to hard copy), and then the jurisdiction manually inputs plan information into the plan tracking system (converting it back to a soft-copy form) based on the submitted paper copy. The challenge in applying technology in this phase is the requirement of jurisdictions to maintain secure, accurate records of land development applications. Digital transfer of the data, although tempting, must be carefully considered and implemented.

Some jurisdictions have experimented with the submittal of plans for review electronically. In these experiments, scanned images or the soft-copy files of the plans are submitted directly to the jurisdiction and posted on the computer data system. Reviewers can then download and review the images (plans) from their individual computers and print only those plan sheets necessary for their individual review. This also permits the jurisdiction to integrate the proposed design into their GIS database, allowing easy access for follow-up questions and review.

Review Phase: ESRA could be a significant improvement during the review process. An electronic submission allows the reviewing engineer to make comments but not change the drawing. It is becoming more acceptable to communicate comments and questions electronically (via either the plan tracking system or e-mail), thus easing the time requirement to reach someone by telephone or to transport comments by mail or hand pickup by the designer.

Reviewing plans on a computer monitor requires the reviewer to make a major change in review approach and technique. Most affordable computer monitors require the reviewer to see a plan in a view smaller than that presented by the paper copy. It is difficult to modify the human approach from reviewing plans displayed on a plan sheet to reviewing plans with a computer monitor. For instance, while it may be easier to review just the drainage design without the interference of other design elements, it is also more difficult to see the infrastructure integration.

Fully integrated electronic submission and review could be a significant improvement on what many view as an excessive and drawn-out process; it can speed coordination and design modifications as well as drastically reduce the expense and time of printing and distributing multiple copies. It is likely that new software tools will be needed to assist the reviewer before electronic review can be successful.

Approval Phase: The procedural aspects of electronic approval are still under legal and methodological evaluation. Although most states have legalized electronic signatures, many jurisdictions do not have corresponding enabling regulations to facilitate this aspect of the plan submission, review, and approval process. There is the natural tendency to distrust the electronic submittal in favor of the current hard-copy originals with legitimate professional signatures.

Given the complex issues—human preferences, legal protections for consultants and jurisdictions, and financial resources available to implement the latest and greatest technology—it may be some time before ESRA is common practice throughout the land development industry.

PUBLIC RESPONSIBILITY IN THE PLAN REVIEW PROCESS

Agencies involved in rezoning review are also involved in technical review. While the reviews are similar, the focus is more detailed and is concerned with design, sizing, placement, and connection.

- Long-range planning generally determines whether the street and system layout adheres to development patterns proposed in the comprehensive plan. Personnel in zoning administration determine compliance with zoning ordinance requirements, such as lot size and density requirements. In addition, the submittal is reviewed for compliance with the design guidelines and standards in the subdivision regulations for street and lot layout, environmental protection and other planning issues. Environmental reviews are often performed by personnel in both sections, as well as in other departments.

■ The public works department typically holds the responsibility for streets, storm drainage facilities, and sewer and water systems. Other elements of a development may also fall within the department's purview, such as conduit systems and placement of survey monuments and markers. However, in some communities, streets may come under the jurisdiction of a separate transportation department or a state-level transportation agency. Similarly, water and sewer systems may be run by a regional authority serving several jurisdictions. A drainage district may also have a separate level of authority. A local or state health department can also have regulations concerning on-site and off-site sewage disposal and the placement of septic drainfields and wells.

■ Fire protection officials are frequently involved in the review of subdivision proposals to ensure that clear and adequate access is provided for emergency vehicles. Placement of waterlines and fire hydrants may also fall under their purview, as well as the monitoring of development activity to assist in locating future station facilities.

■ School districts typically perform an analysis of potential school enrollment generated by new development as a monitoring function.

■ A local parks and recreation department reviews subdivision and site plans to evaluate recreational needs of both the new development and the impact on existing facilities. In some jurisdictions, the subdivision regulations and site plan ordinances contain requirements for the provision of such facilities through either construction or dedication. The nature of any such provision would typically be determined during the rezoning process and reviewed for compliance during subdivision or site plan review. This department may also be responsible for preservation and acquisition of important environmental areas, such as floodplains and wetlands, the control of which may be included in subdivision regulations.

■ A building department is typically responsible for reviewing grading, utility, and construction plans that are included as part of the submittal package. Often, review of the site plan is intended to ensure applicable accessibility criteria have been implemented along with common safety considerations for such things as handrails, fencing, and certain material selections (i.e., no-slip surfaces where appropriate). Further, the building department ensures consistency between the site plan and building plans at utility connection points (building/site interface). This department is also involved in project inspection as the project proceeds through the construction phase.

■ The local gas, electric, and telephone companies are involved in confirming system adequacy, connections, the placement of utility easements, and coordination of construction with street, water, and sewer contractor.

■ The soil conservation district or a similar entity may review grading, storm drainage, and other environmental issues, including E&S plans.

■ The health department reviews submissions generally involving wells, septic systems, swimming pools, and other facilities that propose a potential health risk to the public.

The purpose, focus of design and review, and requirements for each submission (sketch, preliminary, final) differ considerably from jurisdiction to jurisdiction. However, each of these phases is conducted in much the same manner. Plans must conform to ordinance specifications for the particular phase concerning detail, required information, scale, number of copies, and supporting documentation. The package is presented to the coordinating office for distribution to the agencies that will conduct the review. In some jurisdictions, a technician will check the submittal to ensure that it is complete, that is, that it has all the necessary information and studies called for in the ordinance. In several Northern Virginia jurisdictions, the private sector has instituted a completeness check to avoid burdening the jurisdiction with this responsibility. The importance of this step is discussed later in this chapter.

The coordinating agency forwards plans to the agencies on its distribution list, which may be set by ordinance or by office policy. In some municipalities, courtesy copies are sent to elected or appointed officials who represent the area in which the project is located and even occasionally adjoining municipalities especially in areas where regional planning efforts are impacted. Public notice may or may not be required. If notice is required, as with rezoning applications, it may be accomplished by mailing notices to adjoining property owners and posting signs on the property describing the application. Each agency that receives a package is asked to review the submittal and return comments or a marked plan by a certain date. In some municipalities, the coordinating agency is required by law to complete its review and render a decision within a specified time period.

Upon receipt of the comments, the coordinating agency typically meets with the applicant in a postsubmission conference to discuss its own and other agency findings with appropriate staff in attendance. This meeting provides a forum for the land development team to explain the rationale behind its submittal and an opportunity to resolve conflicts between its design and agency requirements through negotiations or revision of the plan. One of three decisions may be rendered after the meeting: (1) An approval means that the applicant is authorized to proceed to the next step and carry plan design to the next level of detail. (2) A conditional approval suggests that the plan is essentially acceptable, but modifications must be made prior to taking the next step. This poses some risks to the development team, since the modifications will be designed in the higher level of detail, without the benefit of the government's conceptual approval. (3) A denial means that the development team must reevaluate its proposal, consider the impact of the agency requirements, and, upon redesign, resubmit the application at the same phase.

In some communities, an expedited procedure has been established for processing revised plans after a decision is issued. Often within a discrete time period the land development team may be permitted the opportunity to work directly with an agency that had problems with the original submittal. Once the issues are resolved and the agency has notified the coordinator of its approval, the design process can move on to its next step. In communities with a large submittal workload, the availability of this process can save time for the developer. If not for this process, it would be necessary to enter the review process at the bottom of the pile. The result of starting anew in the process is significant time delays, which are both costly and frustrating to the developer.

PRIVATE RESPONSIBILITY IN THE PLAN REVIEW PROCESS

Public review and approval of engineering plans are necessary to protect the basic health, safety, and welfare of the public. The public works infrastructure codes and ordinances are generally viewed as minimal standards to be met; however, in practice, they become the standard for design and construction. Conforming to these standards is essential to ensure continuity and compatibility with existing and future infrastructure. The professional engineer exercises additional experience and responsibility for practices common in the industry that may or may not be reviewed by the public sector but are as important to a high-quality project as those elements more precisely defined by ordinance and other references. *In the final analysis, responsibility for project design falls to the registered professional who seals the plan documents.*

The engineer seal on a set of plans certifies the adequacy of the design with regard to public good and safety. Does the engineer seal on a set of plans certify that administrative requirements and procedures for processing these plans have been met? There is no such thing as the perfect plan. Different engineers reviewing the same set of plans will find and miss different technical requirements. What then is the significance of the engineer's seal and signature?

The significance of the engineer's seal and signature is best defined by the state licensing boards. State licensing boards are explicit in the engineer's responsibility to the public: "The primary obligation of the professional is to the public. If the professional judgment of the regulant is overruled under circumstances when the safety, health, property and welfare of the public are endangered, the professional shall inform the employer or client of the possible consequences and notify appropriate authorities" (Virginia Water Control Board, 1992). They also are explicit in stating the engineer's obligation regarding competency: "The professional shall undertake to perform professional assignments only when qualified by education or experience and licensed or certified in the profession involved. . . . The professional shall adhere to all minimum standards and requirements pertaining to the practice of his own profession as well as other professions if incidental work is performed" (Virginia Water Control Board, 1992).

Less explicit is the professional responsibility regarding the administrative as well as technical requirements of each particular jurisdiction. While current practice allows less stringent professional standards of conduct in this area, it certainly behooves the engineer to be informed of the administrative and technical requirements of the jurisdiction in which the engineer is practicing. As with all ethical decisions, engineers sealing and signing the plans must make the decision whether they are fulfilling their professional responsibility. Rarely are engineers cited for neglecting the detailed technical requirements of a design plan unless the public safety is clearly in jeopardy. This does not relieve the engineer of the responsibility to design and submit the best possible plan that to the best of the engineer's knowledge conforms to all codes and ordinances.

Maintenance expense of infrastructure is a major cost to public agencies. This is an important reason why public agencies take a keen interest in adherence to their adopted standards and specifications.

The private ownership of the internal infrastructure being designed can arguably be of less importance for public review and approval than that which will ultimately be the public's responsibility. Since it will be in private ownership, the quality and adequacy will be reflected in the value of the property. However, increasingly, the ultimate owner looks to the public review agency for quality control of the final product. Likewise, often the privately maintained infrastructure systems have an effect on the publicly maintained system. Then, too, it is not uncommon for failed privately maintained systems to have to be taken over by the public. For these reasons, there is little difference in the review process or attention to detail for privately or publicly maintained infrastructure designs.

JOINT RESPONSIBILITY: THE PUBLIC-/PRIVATE-SECTOR RELATIONSHIP

Most jurisdictions recognize the economic benefits of quality development. While it has not always been true, there currently exists a conscious effort on the part of administrators to assist those in the land development profession. Administrators recognize that responsive staff, regulations, standards, review processes, and procedures that support and facilitate land development are more likely to attract the private sector to conduct business in that jurisdiction. A simple, predictable, cost-effective, consistent, repetitive, and efficient regulatory process is seen as a prerequisite for attracting development.

Even so, there is a healthy adversarial relationship between public agency individuals charged with the responsibility to review and approve plans and those professional engineers designing and submitting plans. Many professional engineers believe that their plans need only be given superficial review inasmuch as they are taking full responsibility for the adequacy of their design. They believe they have provided reasonable degrees of safety and adequate public protection (Bright, 1992). On the other hand, the public agency plan reviewer has been given the responsibility to decide when adequacy and reasonableness requirements have been met. Detailed specific design requirements adopted by state and local jurisdictions also require that technical standards be accurately met. Despite this healthy adversarial relationship, the goals of both the private and the public sector are the same: produce the best possible project for the citizen.

PLAN APPROVAL PROCESSING CONSIDERATIONS

Interactions with Citizens

In theory, and in most jurisdictions, the general public has no official role in the review and approval process. However, as noted throughout the text, citizens are often successful in demanding and securing a role, even if only advisory, from their elected leaders.

Notification. Many jurisdictions make notification of the public parties—adjoining property owners, municipalities, and community associations—a requirement prior to or immediately following submission to the agencies for review. Those notices are sent by the applicants or their representatives via registered mail with return receipt request as proof of notification. In addition to the written notification, some jurisdictions require that signs be posted on the property under review, stating the project name, type of case and case number, and a phone number for information. Notifications and postings are means of ensuring that every developer interacts with the immediate community on at least a very basic level by providing neighbors the information necessary to become more informed or involved in the process if they so desire.

Meetings with Citizens. Frequently, jurisdictions require design engineers to meet with citizens as part of the plan submission process. Some jurisdictions have set up formal processes for this. Notices of scheduled hearings and/or plan submissions are often sent by the administrative staff or the developer's representative to interested civic groups, which are then invited to review the plans, discuss their concerns with staff, and attend public hearings to place their comments and concerns on the record. In lieu of attendance at a public hearing, interested parties may submit letters to the approving agency for inclusion in the public record. Since the provisions of the subdivision ordinances and site plan regulations are rarely free from interpretive discretion, citizen comments often serve to influence the review staff, as is the case in the rezoning process. This does not suggest that the development team must employ the same intensity of community relations as for rezoning. However, the team should consider the potential impacts on adjacent property owners and attempt to reconcile them with the developer's own requirements. In practice, those familiar with the community must judge the level of involvement that the residents seek.

Once plans have been submitted, they can be subject to review by citizen groups in the immediate area as well as citizen groups set up for the specific purpose of reviewing development plans. These meetings are generally not in the regulated process and sometimes are seen as delaying tactics by those opposed to the proposed development. Jurisdictions see this process as being responsive to their citizens. It enables citizens to provide input to the project that could overcome objections if discovered later, during or after construction. Opposition can become a major obstacle or result in delayed project approval; therefore, it is prudent to resolve conflicts with neighboring property owners early in the process. Frequently, careful consideration of the road systems and attention to environmental issues (particularly tree preservation), additional screening, and landscaping, setbacks, or other aesthetic devices are sufficient to eliminate opposition. However, it is not always this easy; ameliorating citizen concerns requires keen listening skills in order to pinpoint valid concerns and a thorough understanding of the project design to identify feasible design alternatives. Many jurisdictions have an appeal period built into the approval process; developing a good relationship with stakeholders may diminish the likelihood that someone will appeal the decision of the approving agency.

Some jurisdictions have effectively eliminated the subdivision of land by right and have incorporated its review as a special exception. Where this process has been implemented, the public's concerns have a much more direct impact and the subdivision process takes on an added dimension more closely paralleling the discretionary review of a rezoning application. The significant weight accorded citizen comments in a public hearing places a greater obligation on the development team to identify concerns early in the design process.

The engineer can profit from these meetings by adjusting the design not only to better fit into the community but to gain support for the project. Often, engineers are reluctant to defend their design to nonengineers because they lack the communication skills to convey important design considerations. Engineers need to be better able to communicate their designs to nonengineers in order to maintain the credibility of the profession. This requires sincere listening and then responding to legitimate citizens' concerns. U.S. Senator J. William Fulbright's comments regarding student demonstrations during the Vietnam War is fitting for the engineer:

"The student, like the politician, must consider not only how to say what he means but also how to say it persuasively" (*Washington Post,* 1992).

Meetings with Review Staff

Jurisdictions that encourage communications between the design engineer and the review staff prior to plan development recognize the benefit in attracting quality development. The ability of the submitting engineer to understand the regulatory process and subsequently be able to move plans through the process in a timely manner benefits both the design engineer and the jurisdiction. The uniqueness of the specific plan, sequence of plan type submission, anticipated schedule, and other important elements can also be determined.

A telephone conversation or meeting prior to the preparation or submittal of a plan can be most beneficial. In any event, whenever the engineer lacks knowledge about the process and other in-house professional staff cannot be of assistance, a request to meet with the reviewing agency should be made. It is far better to understand the process in advance rather than have to suffer through it by experience.

Public agency reviewers must have broad technical knowledge as well as knowledge of the review process. They are required to make recommendations on rezoning development plans, sketch plans, preliminary plans, plat check sheets, grading plans, public improvement plans, waivers, subdivision plans, site plans, easement plats, and record plats. They also review and make recommendations on the environmental impact of proposed development and the need for drainage studies, floodplain studies, and soil studies. They determine street design and alignment requirements. They must have a thorough knowledge of the subdivision provisions, the zoning ordinance, road specifications, and other technical and procedural texts. Consequently, a reviewer can reasonably be expected to be able to respond to inquiries of the submitting engineer. However, this does not relieve the engineer from learning the technical and administrative requirements of the jurisdiction in which the engineer is practicing.

Following the initial review of plans, it is desirable to meet with the reviewing authority to understand the comments. This enables the engineer to know specifically what needs to be changed in the plan in order to gain approval. Some jurisdictions arrange to have a representative from all of the reviewing agencies present at one meeting to better coordinate comments. This allows all questions and concerns to be addressed in one meeting with the appropriate officials (International City Manager's Association, 1986). Some jurisdictions make these postsubmission meetings mandatory. In the Virginia suburbs outside of Washington, D.C., the mandatory postsubmission conference agreed to by both public- and private-sector engineers has been touted as contributing significantly to the reduction in the number of submissions necessary for plan approval. A specific format was developed to conduct the meeting (Engineers and Surveyors Institute, 1990).

These meetings between the submitting engineer and the public review staff contribute to the healthy adversarial relationship mentioned earlier in this chapter. The reviewer has the responsibility to ensure that the desired plan changes are properly understood and that the design engineer is willing to make those changes. The design engineer has the responsibility not to compromise the design based on his or her perception of potential harm to the health, safety, and welfare of the public in violation of the professional engineer's plan certification. The design engineer is the client's representative at these meetings and should have a clear understanding of his or her limitations with regard to agreeing to design changes. Of particular concern would be those changes that will have a financial impact or significantly alter the project.

Administrative Requirements

Administrative requirements determine the manner in which plans are submitted for review. Typical administrative requirements dictate the types of plans and the number of copies needed, plan sheet size and standard scale, format of the sets of plans, agencies participating in the review process, the sequence of review, required supporting documentation, and general information needed. Administrative requirements may also specify the need for a construction schedule, a cost estimate, and any time constraints associated with approvals. Since administrative requirements change frequently, it is the responsibility of the engineer to check that the most current issue of the requirements is being used.

Administrative requirements facilitate the review process by standardizing information supplied with all plans. This is most helpful in the review process of large jurisdictions processing large numbers of plans from many engineers and surveyors. Since fewer plans are being processed for review in smaller jurisdictions, there is less need for detailed administrative requirements.

Some jurisdictions require the submission of a checklist indicating the completeness of the plan submission. The checklist lists all the required documents as well as some items that have frequently been omitted in prior submissions. The submitting engineer must check the items supplied and sign the checklist. This serves as a check for the engineer as well as facilitating the review process by ensuring that important documents that would delay the review have not been omitted. A typical checklist is included in the Appendix G for reference.

Some engineers discount the importance of complying with the administrative requirements. They have devoted so much of their time ensuring that the project is designed within the site constraints and complying with technical requirements and economic constraints that the administrative requirements seem trivial. It is important to remember that failure to adhere to these requirements can delay the review process and frequently results in plan rejection or disapproval. Not adhering to the time frames outlined in due diligence requirements can result in the expiration of the plan, necessitating a resubmission or even a new legislative approval.

The public agency rejecting a set of plans will comment on why the plan is being rejected, noting things that need to be done to correct it. These comments are usually written, but they may be verbal. Meetings and conversations with the submitting engineer are helpful in establishing direction to secure plan approval. Once again, failure to follow the suggestions of the reviewing agency can result in the agency continuing to reject the plan. Obviously, the engineer's client can become dissatisfied with the engineer and question his or her competence. While there is no such thing as a perfect plan, following the suggestions of the reviewing agency and maintaining good professional relations increase the likelihood of plan approval.

Partial and Incomplete Submissions

Communities that make a point of checking for completeness before accepting submissions have done so for two reasons: (1) fairness to other developers and (2) reduction of their own increasing workload. Under pressure to get submittals into and through the community's development review process quickly, developers and their consultants often find it convenient to submit partially completed applications. Knowing that an existing backlog of submittals might mean a several-week delay in review, this practice provides the development team additional time to perform or finish a needed analysis or design. By virtue of the date of submittal, the plan is guaranteed an earlier review than plans submitted subsequently, even if the later plans were complete. The practice has often meant that purchase contract or loan commitment requirements could be fulfilled or that construction crews could proceed with minimal interruption.

In some instances, the practice ensured that a plan would effectively be grandfathered from a new regulation or policy. In some jurisdictions, a plan that is designed using the requirements of one regulation often must be redesigned to comply with a subsequently adopted regulation. If that regulation is to become effective in the near future, the development team may need to demonstrate that some progress has been made through the review process. Redesign to ensure compliance with the new rules would cause delays and substantive additional costs. Plans that are formally submitted and accepted by a certain specified date are often grandfathered or otherwise obviated from fully meeting the new requirement—hence, the rush to get a plan into the development review pipeline.

Some communities have found that the practice of submitting incomplete applications is an attempt to elicit design assistance or quality control from the review staff. Knowing that review personnel in various departments would clarify or resolve critical design issues, the development team would submit only partial solutions. Often, this land development equivalent of "run it up the flag pole and see how it flies" led to early abandonment of projects deemed too complex. Meanwhile, local government personnel and resources are tied up with what it deems a frivolous project, when its efforts can be better spent on more serious proposals. Except where it is permitted and encouraged, the land design team should avoid the practice of making incomplete submittals. Some jurisdictions have institutionalized a partial design phase through the use of a preapplication submittal that does not go through the entire approval process, and often has no fee associated with it, to assist the development community in improving design quality. However, in most cases, the practice of submitting incomplete plans damages the reputation of all members of the design team, leading government reviewers to be skeptical of future proposals.

Fees

Fees are usually attached to the review process. These can be a flat fee for each type of plan or study that is submitted or, based on the acreage, the number of lots or the building floor area, linear feet of roads, sanitary sewers, storm sewers and waterlines, cost estimates of public improvements, or some other indicator. These fees in part pay for the government agencies' administrative costs in performing submittal reviews. Practice also varies as to when the fees are collected. Some jurisdictions require fees to be paid with each submission phase, while others require an up-front estimate of the entire development process and maintain an actual accounting of time spent throughout the life of project. Reimbursement of excess fees may be due the developer or additional payment may be required at project completion.

Quality Control

It is unnecessary to say that quality control of the design of a project is the responsibility of everyone taking part in that design. The project manager usually assumes that role during the course of the design. However, recent trends emphasize the importance of quality control being installed into the product from the very beginning.

On the other hand, some clients demand unrealistic time frames for the design completion. This is usually motivated by businesses waiting to move into a new facility or is due to the high cost of borrowing money on vacant land. Time becomes a significant cost factor in these situations. It is this time-sensitive nature of land development projects that makes quality control seem like a nicety rather than a necessity. A hurried design can result in an inadequate design as well as one that is not in conformance with regulations. In more cases than not, time is not saved and the design is more costly in the end.

The typical approach to quality control regarding engineering plans concentrates attention on those plan elements relating to the ability of the project to be constructed efficiently and with sound quality. The design engineer's primary responsibility is to design the project to meet professional standards, and that requires almost singular concentration. The basic design of the infrastructure is the same regardless of jurisdiction. This results in the lack of attention to those plan elements particular to each jurisdiction that must be correct in order to have the plan approved by the various reviewing agencies. There are many chances for error in the plan design and review process. The many different kinds of plans that are required for a specific situation increase the potential for error. In addition, so many persons and agencies are in the review process that the lack of an early identification of conflicting requirements causes problems later in the process. Failure to reduce conflicts results in construction plan approval delay and increases in overall project expense.

Engineers in reviewing agencies are typically trained in the codes and regulations of the jurisdiction in the area specific to their professional expertise. The reviewer sees many plans from that perspective and acquires skill in identifying areas of omission. One can readily see the juxtaposition of the *design engineer concentrating on the quality control of construction elements* while the *reviewing engineer concentrates on those elements specific to that jurisdiction.* The plan elements that the reviewer concentrates on often pertain more to the process than to the design product.

Plans submitted without undergoing a quality control check for both construction and process elements clutter the review system and can result in an inadequate review due to omissions. Some jurisdictions institute a preliminary review of plans before accepting the plans for distribution to the review agencies. This review usually is cursory, sometimes using checklists to ensure completeness in the set of plans submitted. The time taken to review for completeness is relatively short compared to the time necessary for the detailed review. Plans are rejected and returned to the submitting engineer when plan sets are incomplete.

There is a tendency to rely on the reviewing agencies for the design quality control. When this is done, more time is needed to perform the agency review. It also reduces confidence of the reviewing agencies in the submitting engineer that future designs will meet the jurisdiction codes and regulations. It is very tempting for a public agency reviewer to comment on a set of plans with individual preferences as opposed to limiting comments to those supported by specific regulations. Likewise, a public agency reviewer can become zealous in reviewing a development plan, since in most instances the public agency will be the ultimate owner of the infrastructure being designed. Sometimes these comments can become burdensome and costly to incorporate into the design. The time necessary to incorporate comments into the design is also a cost item.

Design engineering firms can improve on the public agency review process by instituting a good quality control program that also emphasizes those plan design elements particular to the individual jurisdiction. This requires that engineers in the organization be trained to review plans in the same manner that agency reviewers do. They need to review plans as if the public agency is the client and their client is the ultimate owner of the infrastructure. They also need to review the development plans as if they were the enforcer of public agency codes and regulations.

Jurisdictions in the Washington suburbs of Virginia have taken an innovative approach to improving the quality of plans being submitted and reviewed by private- and public-sector engineers. A public/private partnership, Engineers and Surveyors Institute, has been formed to conduct education in the plan design and review process. It also conducts a peer review of plans prior to their submission to the jurisdictions as well as a peer review of the comments made by the jurisdiction reviewers (see the typical ESI Checklist in the Appendix G). Design engineers of firms other than the one submitting the plan, as well as an independent engineer, conduct this peer review.

Engineers completing the rigorous initial and annual continuing education program and meeting experience qualifications are certified and entitled to an expedited review process. Discrepancies in the plans being submitted can result in disciplinary action, including eventual disqualification from the expedited review advantage. Plan completeness and quality have improved dramatically. Plans are being approved in one-third the time of previous submittals. The program encourages communication between submitting and reviewing engineers as well as among the various jurisdictions regarding the plan review process and other technical concerns.

Jurisdictional Organization for Review

The agency taking the lead role in performing plan review varies from jurisdiction to jurisdiction. In larger communities, the planning or public works department is given this responsibility. In some instances, a multipurpose agency established to administer building and environmental regulations is sometimes created for this purpose. In small communities, an individual such as the town manager or engineer (sometimes contracted from the private sector) may be responsible for the review process. The designated review agency also is generally responsible for coordinating the review of plans by other governmental and quasi-governmental bodies. In a typical developing jurisdiction, the lead agency distributes copies of the subdivision plan to other agencies for review. Most agencies are asked to review submittals to identify the location, adequacy, and availability of services and assess the impact on systems for which they are responsible. These agencies also review plans for compliance with ordinances and standards that they may administer.

Their role as the technical reviewer is challenging and is to ensure proper relationships among systems constructed as part of the new development and the community's existing and proposed patterns and networks. Some agencies receive copies to assist in monitoring developing activity, thereby aiding in planning and budgeting for personnel and facilities to service future users. Local ordinances frequently define the reporting relationships for this review, specifying whether agency comments are advisory or mandatory to the lead department. The distinction is important to the development team, as the different departments are responsible for individual programs that have varied and sometimes conflicting priorities. It is important to know who has the authority to resolve conflicts when competing demands confront the developer.

Addressing Review Comments

Project plans are distributed to the various agencies for review and a determination as to whether they are in compliance with all appropriate codes. In addition to narrative comments, review agencies often write comments directly on the plan documents. Following all agencies' reviews, the plans are returned to the engineer for corrections. The consultant's task is to determine those review comments that are actual requirements directly imposed by regulation versus those that are subjective recommendations. Sometimes, the comments that appear are simply statements of local ordinance or policy, often without identifying whether the particular submission is flawed. Sometimes the comments are a result of requirements that the reviewing agency is in the process of codifying. The consultant addresses the comments either by revising the design and changing the drawings or by initiating discussions with the reviewer. Good access and rapport should be established and maintained with the lead reviewer at all times. Some comments may appear inconsequential, but if each and every comment is challenged, the relationship and future projects on which the consultant and reviewer may have to collaborate may be jeopardized. However, where some of the comments received appear to be improper interpretations of the regulations, it may be necessary to seek a decision from a supervisor or other authority.

After the land development team has addressed the comments by all of the agencies, the plans are resubmitted for a second review. The resubmission gives reviewers assurances that the initial comments have been adequately addressed and changes properly integrated into the original design. When all of the review agencies have had their comments addressed, the plans are authorized for the next phase of the process. Noted here is the extent of the liability of the municipality and the engineer who sealed the plans. Although the reviewing agencies have approved the plans, the liability of construction rests with the engineer and not with the review agency.

Bonding and Agreements

Upon completion of the review and approval of the construction plans, additional administrative steps are necessary to ensure not only that the infrastructure construction is completed but that it conforms to the approved plans. These guarantees take the form of enforceable bonds and agreements. In most cases, the documents must be processed before the issuing of permits that would allow construction to commence.

The agreement is the legal, binding contract between the developer and the permit-issuing authority. The agreement specifies the manner and date by which the construction as shown on the approved plans should be completed. A bond or other form of security approved by the local jurisdiction backs the agreement.

The performance bond ensures compliance with the terms of the agreement. The bond is usually the full amount of the estimate for construction of the public improvements. The submitting engineer determines the quantities of items subject to bonding and certifies the accuracy of the estimate. For more information on bonding and cost estimating, refer to Chapter 29. The bond amount is a reasonable estimate of what one could expect to pay to have the improvements constructed within the period specified in the agreement. This estimate is reviewed and approved by the local jurisdiction as a part of the approval of the entire bond package. It is not unusual for larger developments with considerable infrastructure construction to develop the project in smaller sections to avoid the financial burden of bonding the entire project.

Upon completion of the physical site improvements and compliance with all other regulations, the bond may be released. Some jurisdictions allow for partial release as elements are completed and accepted. An inspection is conducted to ensure compliance with all previously noted code infractions that all infrastructure construction is acceptable to the agency assuming maintenance responsibilities, all fees have been collected, and the as-built construction plans have been approved.

Some localities require a conservation agreement and bond in order to preserve those parts of the development property that are to remain undisturbed. This is to ensure protection of trees, historic structures, and the like. Accurate identification of these areas is necessary to avoid errors and misunderstandings. The conservation agreement also ensures that the erosion and sediment controls are installed and maintained.

Permits

Based on the approved construction plans, permits are necessary before the initiation of construction. Some typical types of permits necessary would be clearing and grading, erosion and sediment control, demolition, and building permits. Permits alert the locality that construction is about to commence so that inspection can be instituted. It also serves as a safety check that construction is being performed with plans that have not become outdated. It also allows for any special conditions that may be necessary at that particular point in time. Generally, it is the client's or contractor's responsibility to secure permits. The design engineer may be called on to assist in this as needed.

Plan Revisions and Record Documents

It is rare that plans do not need changing once construction commences. Changing field conditions, discovery of previously unidentified information affecting design, changes in the building design, and changing the project due to shifting economic conditions all contribute to plan revisions. The submitting engineer must prepare a formal plan revision and submit the updated plans to the local jurisdiction for approval. Since construction may be under way, quick review and approval are essential. Most jurisdictions give priority treatment to revisions of already approved plans. The procedure for filing the plan revision is often the same as for construction drawings.

Local jurisdictions will want some assurance that the actual construction performed is in accordance with approved plans and revisions. For these reasons, a record document plan (sometimes inaccurately called *as-builts*) is usually required prior to the release of the construction bond. Record document plans show the boundary of the site, location of all buildings, horizontal and vertical location and size of pipes and apertures, location of fire hydrants, location and width of streets, walks, trails, and other improvements as constructed.

Since the engineer has created a revised plan in the form of the record document, he or she is required to certify record document plans in the same manner as design plans. Some agencies require that the engineer certify that the record document plans conform to the approved and revised design plans except as shown. Some difficulty may be experienced with this, depending on what is shown on the record documents. Usually the record document plan is created from the original design documents: "It is the general contractor who is responsible for supervising the day-to-day work on the site; he or she is the only one in a position to identify and record changes made during the course of construction" (DeJarnette & Paul, Inc., 1991). These documents may contain information that was not a part of the record document survey requirement. In this instance, caution is necessary with respect to what the engineer is certifying. A suggested precaution to be stamped on each sheet of the record drawing, subject to review by attorneys, would be as follows:

> These record drawings have been prepared based on information provided by others. The Engineer has not verified the accuracy of this information and shall not be responsible for any errors or omissions which may be incorporated herein as a result (DeJarnette & Paul, Inc., 1991).

As stated previously, record document plans must be approved prior to the release or partial release of the construction bond. For this reason, there is usually a critical time constraint on the development of the record documents.

Durability of Approvals

As noted earlier, completing and securing approval for one phase of the development process typically means that the development team is entitled to proceed to the next stage. However, many jurisdictions place a limit on the length of time that an approval remains valid. This is done to prevent land development projects from spanning several years and be grandfathered from new ordinances and laws. In the course of administering its development regulations, local governments often identify flaws or deficiencies in its regulations. When this happens, it usually takes steps to amend those regulations with new regulations being adopted to protect the health, safety, and welfare of community residents. Plans already in the process are often protected against changes imposed by subsequently adopted regulations. By providing an expiration date on its approvals, the local government can minimize the number of projects that are exempt or grandfathered from new policies and regulations.

Another motive for providing for the expiration of development approvals is to enable the jurisdiction to more accurately monitor its rate and patterns of development. If approvals did not lapse, it would be extremely difficult to make reasonable estimations of growth. Local government would be unable to properly budget for the provision of public services, facilities, or personnel.

While the subdivision and other regulations establish time limits, they also often provide for automatic extensions as well as extensions for extraordinary circumstances. These extensions must often be requested prior to the expiration of the approvals and will themselves have a time limit attached to their approval. Consequently, the land development team must closely monitor the project calendar. If circumstances indicate that a submittal will be delayed or a subsequent approval is not feasible within the time available, it should communicate these concerns to the appropriate officials. A failed opportunity for an extension may result in an expired plan and require a totally new submission, exposing the plan to any and all regulations and ordinance changes approved since the plan was initially submitted. Compliance with new regulations could necessitate a costly redesign and project delay. Additionally, the developer and the land development team should be cognizant of laws requiring that approved developments be constructed or that approved subdivisions be recorded within a specified period of time.

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CHAPTER 31

ENVIRONMENTAL PERMITS

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INTRODUCTION

The land development and construction industry is required to obtain permits for each phase of the development process from land clearing and grading to final construction and occupancy. The majority of the permits required are related directly to the construction activity, building components, and utilities. An environmental permit is a permit that is issued by federal, state, or local agencies for regulated activities to ensure compliance with environmental laws. Although a permit may be required as a result of federal legislation, it may be issued by either federal, state, or local agencies based on interagency (primacy) agreements.

Construction projects have the potential to adversely impact valuable natural resources—land, air, and water. These impacts can cause negative changes in both physical and chemical characteristics of natural resources. Because of the complexity of the natural environment, the land development process requires the input of various environmental professionals with expertise related to the site-specific features of the land to be developed. A parcel of land or a specific construction activity may require one or more environmental permits due to the site location, natural resources present, site features, type of construction, and/or the final use of the facility. Permit requirements can vary significantly based on state and local regulations. The climate and the time of year also can be factors in permitting requirements for specific construction activities such as stream or wetland disturbance and landscaping. Therefore, the developer needs to be aware of the environmental requirements specific to the project and the permitting jurisdiction.

Environmental permits discussed in this chapter are related to land development activities that impact air or water quality or generate noise or waste materials. It is the responsibility of the organization conducting the activity to ensure that all necessary permits are obtained and the permit conditions met. The length and duration of permits issued under federal laws differ depending on the type of permit and specific conditions imposed by the permit. Most environmental permits are issued for 1 to 5 years, with occasional permits issued for 10 to 15 years, depending on the anticipated length of the activity.

Obtaining environmental permits can be a complicated process. The first challenge is to understand the variety of regulations as they relate to the proposed activity and locality. Once the potential permitting requirements are known, the next step is to perform the necessary studies required to complete the permit applications. Permits associated with minimal impacts to the environment are typically referred to as *general permits*. Typically, general permits cannot be modified. The permitting process for general permits can take 30 days to six months. In general, these permits have specific time frames, set conditions, and schedules for the agencies to issue or deny a permit. Therefore, it is in the best interest of a developer to evaluate ways to avoid or minimize impacts to the environment in order to meet the criteria for issuance of a general permit.

Projects that have the potential of causing major environmental impacts that do not meet the requirements of the general permit typically require the issuance of an individual permit. Individual permits are tailored for the specific project and its impacts on the environment. Regulatory agencies do not always have time frames for issuance of individual permits; therefore, it could take six months to several years to obtain such permits. These projects may also require significant studies and documentation to determine the types and magnitude (or significance) of potential environmental impacts. These studies could include National Environmental Policy Act (NEPA) documentation preparation such as a categorical exclusion document, an environmental assessment, or an environmental impact statement (see Chapter 3 for further detail on environmental studies). Projects that could trigger NEPA documentation must have a federal action, which could include projects that use federal funding, require a federal permit, impact a federally listed species, impact a limited access line associated with a federal highway, or impact a federally listed historic property or structure.

PERMITTING PROCESS

The increased awareness of environmental impacts associated with land development has resulted in a more stringent permitting process involving coordination with multiple agencies. If the permitting process is not incorporated into a developer's budget and schedule, it could significantly affect project progress or even stop work altogether. Therefore, knowledge of the environmental regulations and the permitting process is an essential part of a successful land development project.

The permitting process is constantly evolving, and regulatory agencies recognize the need to improve and streamline the process. Permit writers are finding new ways to improve environmental and economic results through innovative approaches to permitting. Some permits may contain incentives to reduce the amount of pollutants or allow for more operational flexibility; however, taking advantage of these incentives can be labor intensive, requiring significant monitoring during the construction and operational phases of a project.

Although the requirements of an environmental permit may vary significantly from state to state, the permitting process is similar. Some permits may be relatively easy to obtain based on the nature of the regulated activity and its potential for minimal effects on human health and the environment. For example, some permits require the applicant to meet a standard set of conditions, complete the application, submit a fee, and within 15 days receive an authorization for coverage under a general permit. The permitting process associated with individual permits is both much more detailed and lengthy. The overall permitting process for both general and individual permits is similar, with the latter typically involving obtaining comments and/or approvals from more permitting or review agencies. The process can be divided into six distinct steps.

Preapplication (Typically Required Only for Individual Permits)

In some states a preapplication meeting with the regulatory agencies is recommended once the preliminary plans for a site have been developed. This meeting assists each party in understanding the other's concerns related to the project, and may save the developer significant time and effort by identifying early on the red flags of the proposed project.

Public involvement plays an important role in the process of obtaining some permits. This can be initiated by holding an informal public meeting, referred to as a *preapplication meeting,* or it can be incorporated into the county or state public communication forum. The purpose of the meeting is to explain to the public the intended activity and its potential affect on the environment, including, if applicable, the specific proposed process associated with the pollutant and/or waste stream that may be generated. The meeting is announced by placing a sign at the site, broadcasting, and/or placing an advertisement in the local newspaper. At the meeting, the organization (applicant) responsible for the activity explains the plans and provides the public with the opportunity to ask questions and make suggestions.

Permit Application

Following the preapplication meeting, the applicant fills out the permit application. Permit applications are often lengthy and may be required to include the following:

- A description of the project, including physical location, existing site conditions, distance to nearest water body, primary watershed, and the outcome of previous coordination with the public or regulatory agencies
- How the facility will be designed, constructed, maintained, and operated to be protective of public health and the environment, including a demonstration of avoidance and minimization strategies to be implemented
- How emergencies and spills will be handled during construction (and for industrial facilities after construction) should they occur
- Where or how mitigation for project impacts will be accomplished
- How the facility will clean up any environmental contamination that could occur during construction
- How public health and the health and safety of the workers involved will be protected if the development site is likely to contain any contamination
- How any waste streams generated during construction will be managed
- If applicable, how an industrial facility will close and clean up once it is no longer operating

Receipt and Review Information

When a permitting agency receives an individual permit application, it notifies the public that it has received the application and places a copy of it in a public area for review. The permitting agency reviews the application to make sure it contains the information required by the regulations. Some agencies do not post the project for public notice until they have made a preliminary decision to issue or deny the permit; in these cases what is posted is the tentative decision.

Revisions

If the permitting agency is not satisfied with the permit application or finds the information submitted to be lacking or insufficient, it may issue a Notice of Deficiency (NOD) or a request for additional information. NODs identify and request that the applicant provide missing or additional information. During the application review and revision process, the permitting agency may issue several NODs. Each time the permitting agency receives a response from the applicant, it reviews the information and, if necessary, issues additional NODs until they consider the application complete. Given the complex and technical nature of the requested information, the review and revision process can take several months to several years to complete, depending on the type of project, the environmental sensitivity of the site, and the type and significance of the anticipated impacts. Therefore, it is in the best interest of the developer to submit permit applications that meet the administrative completeness and technical requirements of the permitting agencies involved in the process.

Public Review (Typically Associated with Individual Permits)

When a permitting agency finds that the permit application is complete and meets applicable requirements, the agency issues a draft permit containing the conditions under which the proposed activity can take place if the permit receives final approval. If the permitting agency determines that an applicant cannot provide an application that meets its requirements, the agency tentatively denies the permit and prepares a *notice of intent to deny.*

In cases of individual permits, the permitting agency announces its decision to the public by placing a notice on its website or in a local newspaper and/or broadcasting it on local television or radio stations. It also issues a fact sheet to explain its decision. Once the notice is issued, the public typically has 30 to 45 days to comment on the decision. The public may request a hearing by contacting the permitting agency. The permitting agency may also hold a hearing at its own discretion. The agency typically gives 30-day public notice before the hearing.

Final Permit

After considering public comments, the permitting agency reconsiders the draft permit or the notice of intent to deny the permit. The agency then issues a *response to public comments,* specifying any changes made to the draft permit. Finally, the agency issues the final permit or denies the permit.

After issuing a permit, the permitting agency may continue to monitor the construction and operation of the facility to ensure compliance with federal and state rules and with the permit conditions.

Several additional steps can also take place after the permit is issued:

- *Permit appeals:* Both applicants and the public have a right to appeal the final permit decision. Administrative law judges usually decide the appeal.
- *Permit modifications:* In the case of construction activities, a permit modification will likely be required if there are increased impacts to the environment. The type of modification (either minor or major) depends on the magnitude of impact increase anticipated. For example, if impacts to a wetland or stream increase a certain amount over the permitted acreage or linear footage, then a modification would be required and the type of modification would be related to the amount of increased impact. Public notice is typically required for major modifications. In the case of industrial facilities, if a facility changes its management procedures, mechanical operations, or the waste it generates or handles, then it must secure a permit modification. For modifications that significantly change the facility operations, the public must receive early notice and have a chance to participate and comment. For minor modifications, the facility must notify the public within a specified period of time prior to making the change.
- *Permit renewals:* The permitting agency can renew permits that are due to expire. Depending on the type of permit involved, permit holders that are seeking a permit renewal may be required to follow the same procedures as a facility seeking a new permit.
- *Permit terminations:* If a facility violates the terms of its permit, the permitting agency can terminate the permit.

REGULATORY ENFORCEMENT

There are various methods used to monitor compliance with conditions imposed under environmental permits. An applicant may be required to monitor or sample discharges or emissions and report the results to the permitting agency. In addition, a permitee is typically required, within a certain time frame, to report to the permitting agency when an activity is not in compliance with the requirements of the permit. The report should contain an explanation of why the noncompliance occurred, how the activity has been brought into compliance, and how the unauthorized activity will be avoided in the future. The regulatory agency may also periodically inspect the permitted facility or site as a means of monitoring compliance.

Federal laws provide federal and authorized state regulatory agencies with various methods of taking enforcement actions against violators of permit requirements. For example, Environmental Protection Agency (EPA) and state regulatory agencies may issue administrative orders that require facilities to correct violations and that assess monetary penalties. Monetary penalties can be severe and can be issued per activity that is noncompliant; for example, a National Pollution Discharge Elimination System (NPDES) permit violation for a construction activity such as not having a Stormwater Pollution Prevention Plan (SWPPP) could result in a minimum fine of $10,000 per day until the SWPPP has been prepared in compliance with the regulation. The laws also allow federal and state agencies to pursue civil and criminal actions that might include mandatory injunctions or penalties, as well as jail sentences for persons found willfully violating requirements and endangering the health and welfare of the public and the environment. If any member of the general public finds that a facility is violating its permit, that person can independently start a legal action, unless the federal or state regulatory agency has already taken an enforcement action. The EPA has an enforcement division dedicated to providing national direction, leadership, and consistency in case selection, development, and resolution and appeal of civil judicial and administrative enforcement actions pursuant to its statutory authorities.

ENVIRONMENTAL PERMITTING PROGRAMS

Environmental permits can be categorized in a wide variety of ways, based on the environmental medium regulated, the regulatory agency administering the permits, or the permitted activity. This section provides brief descriptions of some of the more common environmental permitting programs associated with land development.

Water

For the purpose of addressing water-related permits, this chapter categorizes water into surface water, waters of the United States including wetlands, and ground water. Each of these categories concerns a different aspect of environmental protection and must be managed in a responsible manner to ensure the quality, quantity, and future availability of the resource under consideration.

Surface Water. Surface water pollution can result in conditions that are unsafe for drinking, fishing, swimming, and other activities. Polluted stormwater runoff is a leading cause of impairment to the nearly 40 percent of water bodies surveyed in the United States that do not meet water quality standards (EPA, Office of Wastewater Management). Many studies over the past 25 years have shown that runoff from urban and industrial areas typically contains significant quantities of the same general types of pollutants that are found in municipal wastewater and industrial discharge and cause similar water quality problems (Virginia Water Control Board, 1992). Therefore, as mandated by Congress under the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) stormwater program was created as a national program for addressing the nonagricultural sources of stormwater discharges that adversely affect the quality of our nation's waters.

This permit is required for land development projects on even relatively small sites. Specifically, an NPDES permit is required if the proposed construction is expected to result in the disturbance of more than 1 acre of total land area. Some jurisdictions are more stringent in an effort to protect unique resources; for instance, many jurisdictions in the Chesapeake Bay watershed have lowered the limit for land disturbance to 2500 square feet.

Most states administer the federal program through delegation of authority from the EPA. This is done under regulations adopted by each state and approved by the EPA. Land-disturbing and development activities are required to create stormwater pollutant elimination facilities so as to improve the water quality of receiving streams. For many years, these facilities were required only to minimize soil erosion from entering streams. Nitrogen and phosphorus are pollutants that significantly harm receiving streams. Best management practices (BMPs) are now required in most jurisdictions to prevent this type of pollution. These BMPs can be structural or nonstructural. Refer to Chapter 22 for a more detailed discussion of these facilities. The degree of land-disturbing activity, location of the stormwater management facilities, and their design are the subject of review and eventual issuance of a permit.

The EPA's NPDES permit application process for construction sites is typically mirrored by the states that have been granted issuing authority. Because this is the most common general permit required to facilitate development activities, the process for obtaining this permit, per the EPA's website, is detailed as follows:

1. Read the applicable Construction General Permit (CGP) fact sheet and permit requirements. The applicable CGP depends on the construction operator's NPDES permitting authority. The EPA's national CGP applies only in areas where EPA Regions have not granted the state permit-issuing authority.

2. Develop and implement a Storm Water Pollution Prevention Plan (SWPPP). SWPPPs are required of all CGP applicants. The EPA provides a template for an SWPPP for construction activities on its website, http://cfpub.epa.gov/npdes/stormwater/swppp.cfm. Note that an SWPPP must be developed and implemented in accordance with the CGP prior to submitting the Notice of Intent.

3. Complete and submit a Notice of Intent (NOI) for Construction Activity to the EPA's NOI Processing Center or the appropriate state agency. Signing and submitting the NOI form obligates the permittee to comply with the terms of the Construction General Permit. The EPA's NOI requires certification that the industrial activity will not impact endangered or threatened species protected under the Endangered Species Act. This certification is unique to the EPA's NOI and is not a requirement of most NPDES-delegated states' NOIs. For information about a particular state program or permit, contact the appropriate state.

To terminate coverage, a Notice of Termination (NOT) for Industrial Activity must be submitted to the EPA's NOI Processing Center. A permittee may submit an NOT when:

- Disturbed soils at the construction site have finally been stabilized and temporary erosion and sediment control measures have been removed (or will be removed at an appropriate time).
- Stormwater discharges have been eliminated.
- The permittee is no longer an operator of the site.

Waters of the United States including Wetlands. The Clean Water Act (CWA) is probably the most significant act in its effect on land development activity, particularly the wetlands-related regulations found in Sections 401 and 404. Section 401 of the CWA establishes a program to regulate the effects of any discharges into waters of the United States including wetlands. Section 404 of the CWA establishes programs to regulate the discharge of dredged and fill material into waters of the United States, including wetlands. Waters of the United States considered jurisdictional are regulated by the U.S. Army Corps of Engineers and include streams, wetlands, and open waters (such as ponds and lakes). Wetlands, as defined in Chapter 15, generally include swamps, marshes, bogs, floodplains, and similar areas. Explanation of their importance as a natural resource and their definitions are included in Chapter 15. The simplest strategy for dealing with waters of the United States including wetlands on a particular project is to know the location of the jurisdictional areas and avoid them in the development process. However, in many instances total avoidance is not practical, and some involvement with the regulatory process is inevitable.

Prior to planning and constructing developments within waters of the United States and/or wetlands, the applicant must show that no alternative site exists, that ecological damage will be avoided and/or be minimized as much as practicable, and that there will be no net loss of jurisdictional areas (see Chapter 15 for avoidance, minimization, and mitigation strategies).

As previously discussed in this chapter, the decision of whether a general or an individual permit will be issued is based on the magnitude of the impact on the streams and/or wetlands affected by a project. States may incorporate the permit application process into their adopted water quality regulations. When this is done, it usually results in a simplified process. However, there may be several agencies on federal, state, and local levels involved in issuing and approving a permit. This field of regulation is subject to rapid change, and applicants are advised to seek out the advice of those professionals attuned to the water quality aspects of land development in the site's jurisdiction. Penalties for violating the federal regulations, state law, or local ordinances are severe.

Groundwater. Groundwater accounts for approximately two-thirds of the world's available freshwater supply and is used for drinking water by more than 50 percent of the people in the United States. Groundwater contamination can occur when products such as gasoline, oil, road salts, and other chemicals are released into the environment and enter the groundwater, causing it to become unsafe and unfit for human use. Some of the major sources of these contaminants are storage tanks, septic systems, hazardous waste sites, landfills, and the widespread use of road salts and chemicals.

The Safe Drinking Water Act was established to protect the quality of drinking water in the United States. This law focuses on all waters actually or potentially designated for drinking use, whether from aboveground or from underground sources. The act authorized the EPA to establish safe standards of purity. State governments, which assume this power from the EPA, also encourage attainment of secondary standards (nuisance related). The Comprehensive State Ground Water Protection Programs (CSGWPPs) established a partnership among the states, tribal governments, and the EPA to implement the EPA's groundwater protection goal and principles. State and local governing agencies may have restrictions for development projects that could potentially impact areas that have been designated for wellhead protection.

Air

Air pollution can be defined as the presence of gases or particulates at levels that cause harm to human health or property. Air pollution can be caused by many different sources, which can include naturally occurring events such as windstorms or volcanic eruptions and human-generated activities such as fugitive dust from land disturbance, vehicular emissions, or emissions from industrial facilities. The cumulative impacts of the air pollution caused by these sources can have a significant effect on air quality. The EPA or its delegated state authority has various programs in place under the Clean Air Act to minimize air pollution and protect and improve air quality. The specific standards for air quality vary depending on site location and the activity being performed. The land developer could be required to obtain an air permit and may be faced with addressing issues associated with fugitive dust, open burning, and construction-related air quality impacts. In some instances, a development may be proposed in a National Ambient Air Quality Standards (NAAQS) nonattainment zone (typically related to metropolitan areas). Information about air quality issues at a specific site can be found on either the EPA's website or the particular state's environmental department website. Construction activities in these areas may require additional air permits and mitigation measures. Most states have a state implementation plan (SIP) that incorporates the EPA-approved regulations and other materials for meeting clean air standards and associated Clean Air Act requirements. A project that could have a significant impact on air quality may require extensive air quality modeling in order to verify that it will not significantly increase the constituents that exceed the NAAQS for the respective nonattainment zone. Required mitigation measures could include reduced or restricted work hours or days and restrictions associated with specific types of equipment or construction

TABLE 31.1 State Permit Contacts

STATE	PERMITTING INFORMATION/CONTACTS/LINKS
Alabama	Department of Environmental Management Contacts http://www.adem.state.al.us/OtherInfo/Contacts.htm
Alaska	Department of Environmental Conservation Contacts http://www.dec.state.ak.us/divs_contacts/index.htm
Arizona	Department of Environmental Quality—Permitting http://www.azdeq.gov/function/permits/index.html
Arkansas	Department of Environmental Quality—Permit Summary http://www.adeq.state.ar.us/ftproot/Pub/poa/brochures/02_Permits%20and%20Regulations/ADEQ%20-%20Types%20of%20Environmental%20Permits.pdf
California	California Environmental Protection Agency Contacts http://www.calepa.ca.gov/ContactUs/
Colorado	Department of Public Health and Environment—Environmental Permitting http://www.cdphe.state.co.us/ic/ecashom.html
Connecticut	Department of Environmental Protection—Permits and Licenses http://www.depdata.ct.gov/permit/alphadep.asp
Delaware	Department of Natural Resources and Environmental Control—Permitting http://www.dnrec.delaware.gov/services/permits.htm
Florida	Department of Environmental Protection—Permitting http://www.dep.state.fl.us/secretary/info/permitting.htm
Georgia	Department of Natural Resources—Environmental Protection Division Contacts http://www.gaepd.org/Documents/contact_epd.html
Hawaii	Department of Health—Permits and Licensing http://www.hawaii.gov/health/permits
Idaho	Department of Environmental Quality—Contacts http://www.deg.state.id.us/about/contact_us.cfm
Illinois	Illinois Environmental Protection Agency—Contacts http://www.epa.state.il.us/comments.html
Indiana	Department of Environmental Management—Permits http://www.in.gov/idem/permits/
Iowa	Iowa Department of Natural Resources http://www.iowadnr.com/
Kansas	Department of Health and Environment—Permits http://www.kdheks.gov/environment/download/roadmap_to_environmental_permits.pdf
Kentucky	Department of Environmental Protection—Permitting Program http://www.dep.ky.gov/NR/rdonlyres/A2DDA956-4160-4241-9C8C-EA25266FE0AC/0/EnvironmentalPermittingPrograms.pdf
Louisiana	Department of Environmental Quality—Contacts http://www.deq.louisiana.gov/portal/tabid/62/Default.aspx

TABLE 31.1 State Permit Contacts (*Continued*)

State	Permitting Information/Contacts/Links
Maine	Department of Environmental Protection—Permits, Laws & Rules http://www.maine.gov/dep/permits.htm
Maryland	Department of the Environment—Permitting & Customer Service http://www.mde.state.md.us/permit/index.html
Massachusetts	Department of Environmental Protection—Permitting http://www.mass.gov/dep/service/online/gettings.htm
Michigan	Department of Environmental Quality—Environmental Permits, Licenses & Certifications http://www.michigan.gov/deq/0,1607,7-135-6830-89034—,00.html
Minnesota	Minnesota Pollution Control Agency—Permits http://www.pca.state.mn.us/permits/index.html
Mississippi	Department of Environmental Quality—Permits http://www.deq.state.ms.us/MDEQ.nsf/page/epd_epdabout?OpenDocument
Missouri	Department of Natural Resources—Permits http://www.dnr.mo.gov/forms/index.html
Montana	Department of Environmental Quality—Permitting & Compliance Division http://www.deq.mt.gov/pcd/index.asp
Nebraska	Department of Environmental Quality http://www.deq.state.ne.us/Publica.nsf/Pages/EAD007
Nevada	Division of Environmental Protection—Permitting & Regulatory Requirements http://ndep.nv.gov/admin/guide.htm
New Hampshire	Department of Environmental Services—Guidebook for Environmental Permits http://www.des.state.nh.us/Permitguide/
New Jersey	Department of Environmental Protection—Permit Coordination & Environmental Review http://www.nj.gov/dep/opppc/permitcoor.htm
New Mexico	Environmental Department—Permits, Certifications, & Licenses http://www.nmenv.state.nm.us/permits.html
New York	Department of Environmental Conservation—Permits http://www.dec.ny.gov/permits/363.html
North Carolina	Department of Environment and Natural Resources—Permits, Licenses & Certifications http://www.enr.state.nc.us/html/permitslicenses.html
North Dakota	Department of Health—Environmental Health Section—Contacts http://www.health.state.nd.us/EHS/
Ohio	Ohio Environmental Protection Agency—Divisions, Offices, & Programs http://www.epa.state.oh.us/new/divs.html
Oklahoma	Department of Environmental Quality—Contacts http://www.deq.state.ok.us/mainlinks/contacts.htm
Oregon	Department of Environmental Quality—Permits & Licenses http://www.deq.state.or.us/permitslicenses.htm

TABLE 31.1 State Permit Contacts (*Continued*)

STATE	PERMITTING INFORMATION/CONTACTS/LINKS
Pennsylvania	Department of Environmental Protection—Permits, Licensing, & Certification http://www.depweb.state.pa.us/dep/cwp/view.asp?a=3&g=461114&depNav=l
Rhode Island	Department of Environmental Management—Permits http://www.dem.ri.gov/topics/permits.htm.
South Carolina	Department of Health & Environmental Control—Permits http://www.scdhec.net/egc/admin/html/permtype.html
South Dakota	Department of Environment & Natural Resources—Permits http://www.state.sd.us/denr/onestop.htm
Tennessee	Department of Environment and Conservation—Environmental Permitting Handbook http://www.tennessee.gov/environment/permits/
Texas	Commission on Environmental Quality—Permits, Licenses, & Registrations http://www.tceq.state.tx.us/nav/permits/
Utah	Department of Environmental Quality—Online Permitting http://www.deq.utah.gov/Online_Permitting/index.htm
Vermont	Agency of Natural Resources—Environmental Permit Information Summary http://www.anr.state.vt.us/dec/permits.htm
Virginia	Department of Environmental Quality—Permits http://www.deq.state.va.us/permits/homepage.html
Washington	Department of Ecology—Environmental Permitting http://www.ora.wa.gov/permithelp/default.asp
Washington D.C.	District Department of the Environment http://ddoe.dc.gov
West Virginia	Division of Environmental Protection—ePermitting https://www2.wvdep.org/eplogin.cfm
Wisconsin	Department of Natural Resources—Permits http://dnr.wi.gov/permitprimer/
Wyoming	Department of Environmental Quality—Contacts http://deq.state.wy.us/admin/contacts.asp

materials. A developer should consult with the local jurisdiction on what measures may be required so as to plan accordingly.

Fugitive Dust. The EPA or its designated local authority currently regulates fugitive dust on construction sites larger than 5 acres. Contractors must file a *fugitive dust emission control plan* to be in compliance. Smaller sites may be subject to local regulations.

Fugitive dust control strategies are detailed in Chapter 27.

Noise

Noise is considered a pollutant and can also be considered a public nuisance. While its physical and emotional effects are difficult to define quantitatively, the noise level itself can be measured in decibels and is therefore regulated through permits. Cities and local municipalities typically handle noise issues through local ordinances, so specific requirements can vary significantly, depending on location. The characteristics and conditions that are generally considered when determining whether a noise is a public nuisance include:

- Noise intensity level (commonly measured in decibels)
- Nature of the noise (natural versus unnatural)
- Origin of the noise

- Proximity to receptors
- Time of day (or night) when the noise is generated
- Duration of the noise
- Whether the noise is recurrent, intermittent, or constant

These characteristics are typically evaluated during the plan approval process. If an environmental study has been deemed necessary during the permitting process, a noise impact assessment may be required. The noise impact assessment evaluates the potential effect of the noise on local receptors such as residential buildings, schools, and offices. In addition, the study also evaluates the effectiveness of various mitigation measures that can be incorporated into the project and proposes adequate mitigation to address the magnitude of the impact anticipated. A noise impact assessment would likely be required if there are a significant number of receptors impacted or if a federal action is triggered by the project at hand.

Waste

Waste is generated at construction sites where there is clearing, excavation, construction, renovation, or demolition of structures. This waste is considered construction and demolition debris. Some of this debris can be managed on-site. The remaining waste must be properly handled: either recycled, diverted and reused, or ultimately disposed of at an appropriate permitted landfill. For example, uncontaminated rocks, bricks, concrete, road demolition debris, and dirt are not subject to solid waste regulations and therefore do not have to be disposed of at a landfill. This debris may be reused, recycled, or buried on-site, or it may be removed from the site to be used as off-site fill as long as it is not placed in a waterway or wetland.

New construction, especially on previously undeveloped land, can generate vegetative waste that may be banned from solid waste landfills. These wastes may be disposed of at a composting facility or dealt with on-site by burning, chipping, grinding, or shredding. An air permit may be required if the waste is burned on-site and a registration process may be required if it is to be chipped, ground, or shredded, depending on the quantity of vegetative waste generated.

Contaminated or otherwise classified materials (i.e., classified by the Resources Conservation and Recovery Act, or RCRA) such as contaminated soil, groundwater, asbestos-containing materials (ACM), or lead-based paint (LBP) often require special attention during land development projects. The contractor or applicant is often required to identify the ultimate (permitted) repository and establish demolition, transport, and disposal plans in compliance with applicable regulations.

State Permitting Contacts

Determining the types of environmental permits that are required on a construction project can be a very complex and time-consuming process. Some permits are handled by federal agencies, while others are the responsibility of the individual state or local municipality. To obtain additional information on federal programs, search the EPA website under the names of the aforementioned programs. Table 31.1 provides a list of website addresses for permitting information by state. Most states have posted a comprehensive list of the environmental permits required for varying activities and the appropriate contact should additional information be required.

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CHAPTER 32

BUILDING PERMITS

Lawrence A. McDermott

Updated/Revised: George A. Wigfield, PLS

INTRODUCTION

Subsequent to subdivision or site plan approval, and even in situations where no such approval is necessary, building permits are typically required for the construction of all structures, whether dwellings or nonresidential uses. The assumption is that no new property lines are being created and the primary focus of review is architectural and structural design, accessibility (where required), and connection to existing streets and other public infrastructure facilities. Building permit review allows for examination of criteria contained in both the zoning ordinance and the building codes applicable in the jurisdiction.

BUILDING PERMITS: REQUIRED SUBMITTALS

A building permit application is, in many jurisdictions, the marriage of architectural plans and final approved site or subdivision plans. Most municipalities prepare preprinted application forms and checklists (see Figure 32.1*a* and *b*) showing the information and plans that are required for the building permit submission. The complexity of required documents is contingent upon both the project and type of construction. A general summary of building permit application packages is as follows:

- For individual single-family detached structures, simple lot grading, foundation, and framing plans may be sufficient. Depending on the size of the structure, preparation by an architect may not be required.
- For residential subdivisions, overlot grading plans showing connections to utility systems, soils information, and test data showing areas requiring special treatment or alternate details for nontypical situations, as well as master architectural documents showing foundation and framing plans for each type of house and structural connection details are generally required. The municipality normally performs inspections at the completion of each phase of building construction prior to allowing work to be concealed—for example, closing in a wall before the electric and/or plumbing in the wall have been inspected and approved, in preparation for the next phase.
- For complex residential (i.e., multifamily or mixed-use applications) and nonresidential structures, a complete set of construction drawings—architectural plans and site plans—showing all utility connections and internal systems is often required. Local regulations often establish elaborate testing and inspection procedures with, in some instances, provisions for third-party inspection by independent firms.

PERMIT REVIEW CRITERIA AND PROCEDURE

Building permit applications are reviewed for compliance with appropriate municipal zoning requirements, local, state, and federal building codes, and other applicable regional and municipal regulations such as certain energy efficiency standards that have been codified or green building certification criteria that the municipality has adopted. For zoning, the primary concerns are proper setback from property lines, area of building coverage, density and floor area, height, parking, and other required facilities that support or are accessory to the principal use of the property. Determining compliance with the building codes requires extensive analysis of construction details to ensure structural integrity and review of internal systems for heating, plumbing, and elec-

PRINCE GEORGE'S COUNTY *DEPARTMENT OF ENVIRONMENTAL RESOURCES *PERMIT OFFICE
9400 PEPPERCORN PLACE, SUITE 600, LARGO, MD 20774, 301-883-5900
APPLICATION FOR PLAN EXAMINATION AND PERMIT

Case Number	Year	Type	Rev.:	Date

Site Information	Land Tax Account #	Election District	Lot	Block	Parcel	Tax Map	Grid

Address	Liber	Folio	SCD #
City/Town/State/Zip	Subdivision		Suite/Unit #

Type of Permit Please Check One		Existing Site Use Please Check One	
☐ New Residential	☐ Misc. Residential	☐ OPEN LAND/VACANT LOT	☐ Single Family Dwelling
☐ New Commercial	☐ Misc. Commercial	☐ Commercial Building	☐ Townhouses/Apt/Condo's
☐ Addition	☐ Alteration/Repairs	☐ Grocery Store	☐ Shopping/Center/ Mall
☐ Grading	☐ Logging	☐ Warehouse/Storage	☐ Car/Sales/Wash/Repair
☐ Found/Bldg.	☐ SWM/Concept/	☐ Hospital	☐ Library/School
☐ Use & Occupancy (U&O)	☐ Temp U&O	☐ Church/Rectory/Synagogue	☐ Parking Lots
☐ Sign (Bldg)	☐ Sign (Ground)	PROPOSED USE:	

		Property Information		
☐ Fire/Alarm/Hood	☐ Fire/Sprinklers	Water	Sewer	Electric Co.
☐ Mechanical	☐ Spec./Other/Raze			
Property Owner Information		☐ WSSC	☐ WSSC	☐ PEPCO
Company Name		☐ City	☐ City	☐ B.G.E
Name:		☐ Well	☐ Septic	☐ SMECO

Property Owner Information (cont.)	Work Description & Job		
Address:	Height (ft)	Width (ft)	Depth (ft)
City/State/Zip	Total Site Area	Disturbed Area	Floor Area
Telephone Number	Est. Construction Cost $		

Contractor's Information	U&O Occupant's Information
License Type & Number	Company Name
Company Name	Trade Name
Name:	Owner's Name:
Address:	Address:
City/State/Zip	City/State/Zip
Telephone Number	Telephone Number
Fax Number	Fax Number

Architect's/Engineer's Information	Applicant's Information
Company Name	Company Name
Name:	Name:
Address:	Address:
City/State/Zip	City/State/Zip
Telephone Number	Telephone Number
Fax Number	Fax Number

FOR OFFICE USE ONLY

Agency	Reviewer	Date	Agency	Reviewer	Date
M-NCPPC			Structural. Eng.		
DPW&T			Electrical Eng.		
PERMITS			Fire Eng		
HEALTH			Site Eng.		

Applicant Signature — Date — Permit Specialist

I hereby certify that I have authority of the property owner to make this application and that the information is complete and correct, and if a permit is issued, the construction and or use will conform to the building code, the zoning ordinance and other applicable laws and regulations including private building restrictions, if any, which relate to the property

5066/2004

FIGURE 32.1 Sample building permit application form.

Residential - Single Family Dwellings
The following plans are required to apply for a Single Family Dwelling permit:
•One (1) Concept Approval Letter
•One (1) Approved Stormdrain Plan (if needed)
•Six (6) Site/Plot Plans - Signed and Sealed
•Two (2) Architectural Drawings - Signed and Sealed
•Two (2) Structural Drawings - Signed and Sealed
•Two (2) Landscape Plans
•One (1) Sediment Control Plan - Green stamp if the disturbed area is greater than 5,000 sq. ft.
•Three (3) Tree Conservation Plans or exemption letter

Commercial - Multi-Family Dwellings
The following plans are required to apply for a new multi-family dwelling building permit:
•One (1) Concept Approval Letter
•Seven (7) Site/Plot Plans - Signed and Sealed
•Two (2) Architectural Drawings - Signed and Sealed
•Two (2) Structural Drawings - Signed and Sealed
•Two (2) Electrical Drawings - Signed and Sealed
•Two (2) Mechanical Drawings - Signed and Sealed
•Two (2) Energy Calculations - Signed and Sealed
•Two (2) Landscape Plans - Signed and Sealed
•Two (2) Sediments Control Plans, one (1) green stamped
•Three (3) Tree Conservation Plans, or exempt letter
•Two (2) Approved Stormdrain Plans
•Two (2) Geo Technical Reports

Commercial - Townhouse
The following plans are required to apply for a townhouse building permit:
•Seven (7) Site/Plot Plans - Signed and Sealed
•Two (2) Architectural Drawings - Signed and Sealed
•Two (2) Structural Drawings - Signed and Sealed
•Two (2) Electrical Drawings - Signed and Sealed
•Two (2) Mechanical Drawings - Signed and Sealed
•Two (2) Energy Calculations - Signed and Sealed
•Two (2) Landscape Plans - Signed and Sealed
•Two (2) Sediment Control Plans, one (1) green stamped
•Three (3) Tree Conservation Plans, or exempt letter
•Two (2) Approved Stormdrain Plans
•One (1) Concept Approval Letter

Commercial - New Building
The following plans are required to apply for a new commercial building permit:
•Seven (7) Site/Plot Plans - Signed and Sealed
•Two (2) Architectural Drawings - Signed and Sealed
•Two (2) Structural Drawings - Signed and Sealed
•Two (2) Electrical Drawings - Signed and Sealed
•Two (2) Mechanical Drawings - Signed and Sealed
•Two (2) Energy Calculations - Signed and Sealed
•Two (2) Landscape Plans - Signed and Sealed
•Two (2) Sediment Control Plans, one (1) green stamped
•Three (3) Tree Conservation Plans, or exempt letter
•Two (2) Approved Stormdrain Plans
•One (1) Concept Approval Letter

FIGURE 32.1 (*Continued*)

tric service. Building spaces, both interior and exterior, are assessed in terms of the accessibility guidelines. Fire protection systems and fire code construction standards are also reviewed.

As with other approval procedures, the designated lead agency receives plans and distributes them to others. The review is usually conducted in a single phase, although various components of the structure may be reviewed by different departments or agencies. In addition to the payment of application fees, other fees may also be collected at the time of submittal. These include availability or connection charges for utility services. Fee calculations may be based on floor area, number of fixtures, projected usage, or other indicators. In some communities, impact fees or other development contributions (school contributions, parks and recreation, or public facility contribution, to name a few) also are collected at the time of permit application.

An approved building permit and payment of associated fees gives the owner/developer the legal authorization to start the construction of a building project in accordance with approved drawings and provisions. On the whole, a building permit is required to erect, install, extend, alter, or repair a building and must be posted in a conspicuous place until the job is completed and passed as satisfactory by a municipal building inspector.

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PART VII

CONSTRUCTION

STEP 7: CONSTRUCTION

Construction is the final step in the land design process: it is the phase where the project truly comes to life and all design efforts are realized in tangible form. Although the contractor typically becomes the lead consultant at this stage, the land development consultants—engineers, surveyors, and planners—remain valuable resources. Specific construction phase services vary among projects and clients, often depending on the capabilities of the general contractor, the project schedule, and the budget. When possible, it is recommended that the land development consultant be retained throughout construction to facilitate project completion and ensure correct implementation of design strategies. Inevitably, despite everyone's best efforts during the actual design phases, issues will arise during construction. Whether it is discrepancies between field conditions and plans or between two different consultants' plans (i.e., site plans and building plans), the land development consultant who has been involved in the project from the beginning is more suited to resolve these problems amicably before they escalate into what could be costly change orders or revisions to the development program.

Construction phase services could include:

- Surveying
  - ☐ Construction stakeout surveys.
  - ☐ As-built surveys (although technically a postconstruction service, this is often scoped as a construction service and as such is discussed here).
- Engineering
  - ☐ Shop drawing or product submittal review and approval.
  - ☐ Requests for information (RFI) review and approval.
  - ☐ Inspections, depending on the jurisdiction and their inspection program and particularly if custom design facilities are installed.
  - ☐ Field revisions, which often are minor in nature and are, in the opinion of the engineer, in substantial compliance with approved plans. They are typically accomplished through small exhibits and reflect a coordinated effort between the contractor, client, engineer, and jurisdictional inspector, if present.
  - ☐ Formal revisions to the plan may be required in order to accommodate substantial changes that do not retain the spirit or intent of the approved design documents. Formal revisions are processed through the approving jurisdiction and ensure that the project, client, and contractor remain in compliance with local standards, regulations, issued permits, and binding agreements.
- Planning
  - ☐ Compliance monitoring in terms of ensuring that final development and construction meet the merits of rezoning or entitlement requirements during the course of any revisions or modifications.
- General
  - ☐ Green building documentation services. If formal third-party certification is a project priority, additional documentation and submission of construction-related efforts may be required.

□ Postconstruction services ranging from bond reduction and release documentation to occupancy permit procurement and public street acceptance are all punch-list-type items that land development consultants often facilitate, given their familiarity with the project and jurisdictional requirements.

□ Operations and maintenance training and education for infrastructure systems. As consultants move toward providing project life cycle services, this postoccupancy requirement takes on larger significance: from initial user education to dynamic as-built project logs (drawings linked to databases) such that owners, operators, and/or maintenance personnel have not only a record of what was built, but the ability to access and store information—maintenance or replacement logs, complaints, ownership notes, and so on—on individual site and building features.

Construction, postconstruction, and postoccupancy land development services are evolving at a rapid pace. Hastened by improved technologies, computer applications, and the implications of synergistically designed infrastructure systems, these services represent the next step in comprehensive, client-focused project delivery.

CHAPTER 33

CONSTRUCTION STAKEOUT SURVEYS

Mary Munson Rouse Root, LS

Updated/Revised: Devin M. Keeler

INTRODUCTION

While land planners and engineers propose a manmade order of interweaving utility networks, roads, and buildings, surveyors bring the plans to reality. The surveyor executes the mathematical calculations associated with the construction of the site and the field surveys that accurately reflect these calculations. Legal and practical standards demand precision in two directions simultaneously: the horizontal and the vertical. To fulfill these requirements, a surveyor must research the existing land records, apply coordinate geometry, and prepare a boundary and topographical survey before any site construction can commence. In construction stakeouts, surveyors align the design intentions with the field conditions and provide a last line of defense against potentially costly design errors. A licensed professional surveyor must interpret and implement various federal, state, and local laws and restrictions; satisfy legal and ethical State Board requirements; and produce trustworthy data. Once the plans are finalized and construction contracts are awarded, surveyors then begin the construction layout process.

Three frequently used terms relating to construction surveying are *location, stakeout,* and *as-built.*

Location refers to the type of survey where a specific existing feature is measured both horizontally and vertically from known control points. The data is then computed, plotted, and incorporated into the design.

Stakeout is the field process in which the surveyor provides in-ground reference markers for the builder, which physically delineates the placement of utilities, streets, and buildings. Construction stakeout, or layout, is necessary in every phase of construction, from the initial clearing of the site through the setting of final property corners.

As-built refers to a postconstruction survey of a site, usually performed after the utilities are installed or the buildings are erected. As-built surveys, their importance, and their specific requirements are discussed in detail in Chapter 34.

Typically, the construction stakeout sequence begins with clearing and rough grading stakeouts, followed by stakeouts for the utilities—sanitary, storm, and waterlines—as well as the curb and gutter, building footprints, power and communications equipment, stormwater management facilities, pavement, and property corners.

This chapter outlines the typical construction stakeout procedures and technologies employed by today's surveyors. However, it should be noted that developing technologies have the potential to radically alter the construction stakeout process. Recent advances in the use of global positioning systems (GPS) have revolutionized the construction stakeout process. Specifically, the advent of real-time kinematic (RTK) GPS has allowed surveyors to perform construction stakeout surveys with unprecedented speed and accuracy. Construction companies have also been quick to recognize the benefits of RTK and have begun attaching the units directly to their earthmoving equipment in a process called *machine control.* The on-board RTK unit can inform the operator where more cut or fill is required to achieve the proposed (designed) ground elevations. This technology has the potential to reduce or eliminate the role of the surveyor for basic things like mass grading. However, it also presents an opportunity for the surveyor to support these systems, as construction companies have not fully realized the level of sophistication these systems require to establish and maintain. The surveyor may also be called in to as-built the grades at critical points after the machine control work has been concluded to validate the work performed.

Construction Stakeout Fundamentals

Stakeout Markers. For construction purposes, the marker of choice usually consists of a hub, a tack, and a stake. A hub is a 2-inch by 2-inch wood peg, approximately 8 inches long, with a pointed end that allows it to be easily driven into the ground. The hub is driven flush with the ground. The measurement point is indicated by a surveyor's tack, which is driven flush into the hub. The vertical point of reference coincides with the highest part of the hub. In data collection, the tack is located horizontally and vertically, and this is duly noted in the surveyor's notes. A stake, made of plastic or wood, is a slat with one pointed end to be driven into the ground. It bears written information expressed in symbols, numbers, and abbreviations, and it marks, or *guards* the true horizontal and vertical point, which is the hub. The guard stake is placed such that the side with the offset distance faces the item being staked. Other types of markers used in stakeout include steel bars, spikes, nails with flagging or washers, chiseled marks in concrete, and drill holes. (See Figure 33.1.)

Stakeout markers and accompanying information are used to indicate points of construction to the contractor but may also be used as reference control points for subsequent surveys. Job sites are replete with construction activities, and as a result the hubs and guards are often buried, dug up, or otherwise disturbed. Frequently, this cannot be avoided. Cooperation between the surveyor and the contractor is necessary to schedule the construction stakeout for a specific phase and to place the stakes in areas where they are not prematurely disturbed by other construction activities but remain in areas convenient to the contractor.

FIGURE 33.1 Hub and tack with guard stake. (Photo courtesy of Sam Dougherty/Steve Hall)

Offsets. If the stakeout markers were placed on an actual centerline, they would be lost as a result of excavation and/or grading and general construction traffic. Therefore, stakeout markers are set along lines parallel or concentric to actual centerlines to preserve vital reference points. The distance from the actual centerline to the stakeout line is the *offset distance*. The offset's length is controlled by depth of excavation, width of the excavating machinery, the location of construction materials, traffic, and sometimes by governing authorities. The offset distance is marked on the guard stake, and the position of the offset is labeled left or right as determined by the direction of the increased stationing.

The offsets must remain undisturbed, but not too far for convenient use. Quite often a contractor will request a specific offset distance. When the work is ordered, it is wise to confer with the supervisor upon arrival at the site. The plan and profiles should be consulted to determine the amount of cut, as that determines the top width of the trench and the amount of excavated earth that will be piled adjacent to it. (See Figure 33.2.)

Offset stakes are typically labeled in this order: distance of offset, identification of object being offset, and the station. Vertical information is written on the back of the guard stake. Symbols and abbreviations are typically used. Some examples are provided in Table 33.1.

Stationing. Stationing is a method of designating distances from known points on the site, usually measured in multiples of 100 feet. The beginning point is typically designated as station 0, written as 0+00. A point 100 feet away would be station 1, written as 1+00. However, to avoid the use of negative stations (e.g., −1+50), the beginning station is sometimes designated as an arbitrary full station other than 0 (e.g., 10+00). Stations at even multiples of 100 feet are considered full stations. Intermediate points between full stations are called *pluses;* for example, a point 34.23 feet from station 1 is station 1+34.23 (pronounced as station "one plus thirty-four point two three"). Stationing is the common method used on centerlines of streets and utilities and along the baselines of streams. For sanitary sewer systems, storm sewer systems, and streams, a common practice is to orient the stationing system such that the stations increase in the upstream direction.

An equality is used at points of intersections or to designate a change in the station numbering system. For example, a point of concern occurs when a waterline crosses over a sanitary sewer line. An equality is used to correlate the stationing of the sanitary line with the waterline. That is, the equality consists of equating the waterline station to the sanitary sewer

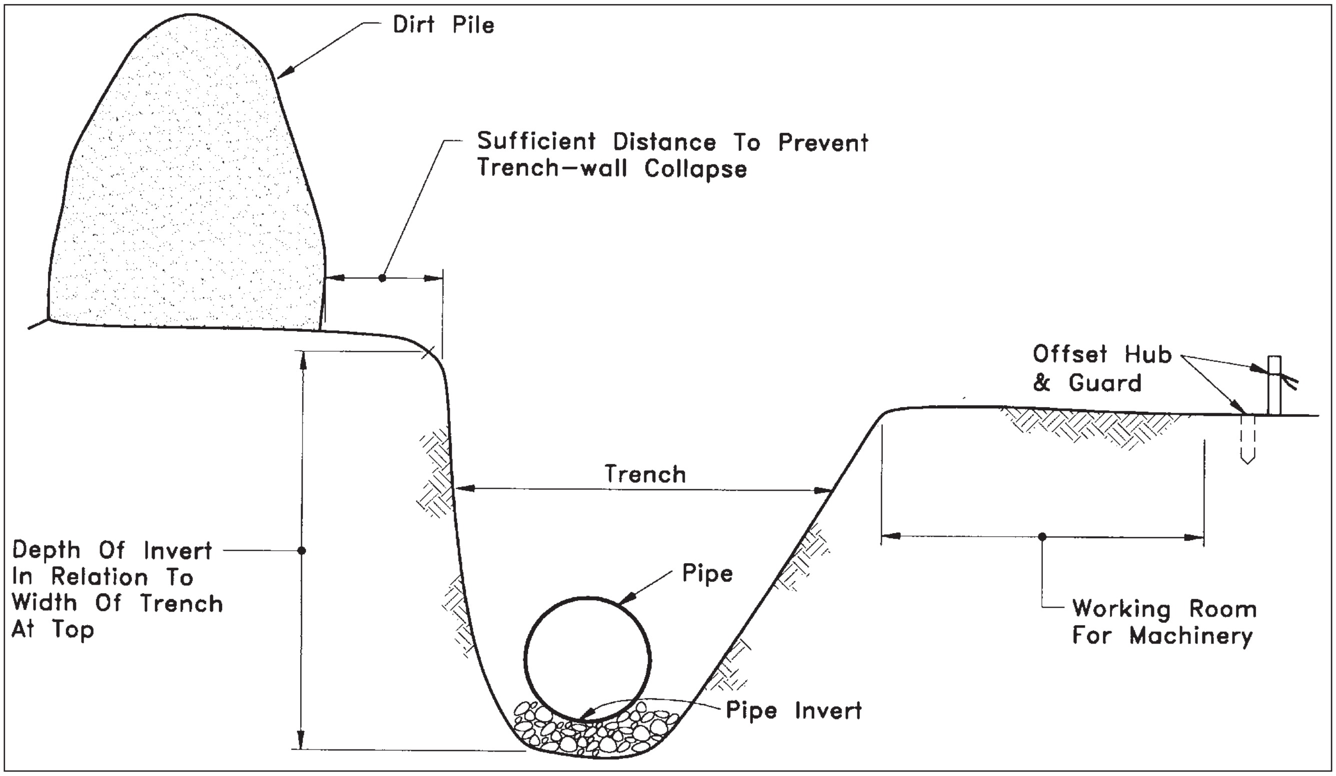


Figure 33.2 Open trench, pipe invert, and offset line.

station at the point where they cross each other. Equalities are also used at street intersections. For example, a station equality is shown at the point where the two streets intersect, which identifies (i.e., *equates*) the station street to the station of the intersecting street. An example of a station equality of two intersecting streets is 9+03.2 CL Main Blvd = 10+00 CL Crossing Drive. (See Figure 33.3.)

Leveling Methods

Once the offset hubs are set, their elevations are established to create a vertical reference for the contractor's use. Most construction stakeout elevations are obtained by trigonometric leveling and GPS but can also be determined by differential leveling and three-wire leveling

Trigonometric Leveling. Trigonometric levels can be accomplished using a total station, prism pole, and data collector. This type of leveling applies the properties of a right triangle to determine differences in elevation. As shown in Figure 33.4, the vertical angle between the instrument's horizon line and an intercept of the rod or prism is measured. The slope distance is also measured. With this information, the opposite side can be calculated and the prism height or rod intercept height applied to obtain the difference in elevation between the point where the prism/rod is being held and the instrument's horizon line.

GPS Leveling. GPS equipment can be used to directly determine the elevation of any point. GPS has long been used for establishing elevations on control points. This would be done using multiple observation periods of 30 minutes or longer. In the past, these control points established by GPS around the site would then be further extended using conventional total station methods. However, recent advances in RTK GPS surveying techniques have progressed to the point that an acceptable accuracy can be obtained for use in the construction stakeout process.

An RTK system consists of two GPS units: a base station and a rover. The base station is placed on a prominent, high-quality control point where it will remain during the day's work. Typically, each site has a designated control point to be used by the base station. For continuity throughout the project, this should be the only control point used as the base station. Therefore, the control point selected should be placed away from construction activity so as not to be destroyed. The rover is free to move about the site to perform the necessary location or stakeout survey. The two units are constantly receiving GPS signals but are also exchanging that information with each other via radio signals or cell phone transmissions. The rover, equipped with the data collector, can then combine both GPS signals to produce a high-quality result in both the horizontal and the vertical direction. The virtual reference system (VRS) is the next extension of the RTK concept. A VRS system is a series of GPS reference stations, located throughout a relatively large geographic region (such as a county, state, or group of states), linked together by a software solution via the Internet. The rover is also linked to the system via the Internet using wireless technology and is provided real-time data and corrections from the network of GPS reference stations. Rather than the single (site-anchored) base station used in traditional RTK surveying, this system establishes a *virtual* reference station on the job site.

TABLE 33.1 Surveying and Mapping Symbols and Abbreviations

AHD	Ahead	⩓	Instrument,	RF	Right Front
∡	Angle		Instrument Operator	RR	Right Rear
∡PT	Angle Point	INTX	Intersection	Ø	Rod/Chain Person
⊠	Area in Square Feet	INV	Invert	SAN	Sanitary Sewer
@	At	LF	Left Front	SAN LAT	Sanitary Lateral
BK	Back	LR	Left Rear	S/O	Stakeout
BM	Benchmark	⋈	Notekeeper	STA	Station
⊠	Benchmark	#	Number	STM STR	Storm Structure
℄	Centerline	0/S	Offset	ST	Street
COR	Corner	⊗	Offset	⊡	Square Point
⊻	Cut	-¦-	Planetable Setup	TAN	Tangent
Δ	Delta	PC	Party Chief	TBM	Temporary Benchmark
EP	Edge of Pavement	PC	Point of Curve	TB	Toe of Bank/Top of Bank
ES	Edge of Shoulder	PI	Point of Intersection	TS	Toe of Slope/Top of Slope
FC	Face of Curb	PRC	Point of Reverse Curve	TC	Top of Curb
⊼	Fill	PT	Point of Tangent	△	Traverse
⋇	Grade	POC	Point on Curve	⚠	Traverse Line
GB	Grade Break	POL	Point on Line	TP	Turning Point
Δ/2	Half Delta	PCC	Point of Compound Curve	VERT ∢	Vertical Angle
HI	Height of Instrument	PCTC	Point of Curve, Top of Curb	W/L	Waterline
Hor	Horizontal	ℙL	Property Line	WS	Water Service
HSE	House	RAD	Radius		

Differential Leveling. This procedure consists of running a level circuit between a minimum of two control points and obtaining rod readings on the hubs as the circuit progresses. The level circuit itself is a series of adding and subtracting rod readings to obtain differences in elevation. Once the height of the instrument (HI) is established, any subsequent rod shot need only be subtracted from the HI to determine the elevation of that point (see Figure 33.5). In construction stakeout surveys, the observations of a number of offset hubs may be made from one instrument setup, but these elevations are technically unproven since they are side shots and not a contiguous part of the run. Therefore, key points of the stakeout are *turned* upon in the course of the level circuit. A *turn* consists of reading the rod on a stable point, changing the height (and location) of the instrument as needed, and reading the rod again. As part of a continuous level run, the turn is an integral arithmetical component and is proven by the final check-in at another known benchmark. (See Figure 33.6.) Successful turns should be balanced, using roughly the same distance for backsight and foresight, to eliminate any adjustment error in the instrument. When reading high on the rod, the rod can be rocked gently to and from the instrument, allowing the instrument operator to read the smallest gradation on the rod and thereby eliminating the error created by an out-of-plumb rod.

Leveling notes are kept in columnar form, using standard survey field-book paper. Each column has a set function in the notes, and the facing page, which is gridded, is reserved for sketches and/or additional descriptions. (See Figure 33.7.)

When job-site benchmarks are established, they must be set in practical locations safe from harm. They must also possess an accurate elevation, proven by inclusion as a turning point in a level circuit, which should produce an accept-

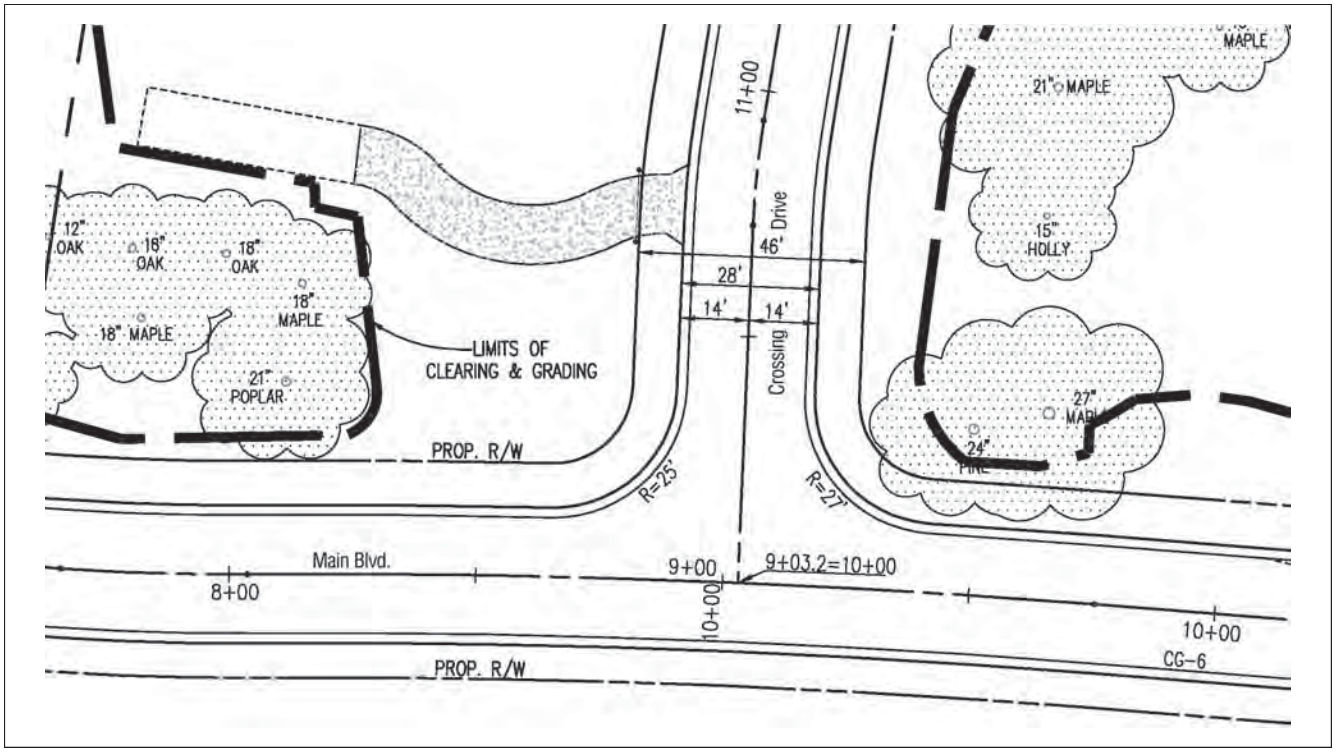


FIGURE 33.3 Example of street stationing.

able closure. Recommended benchmark locations include a nail or spike driven into a saved tree, a corner of an existing storm structure, a flange bolt on a fire hydrant, or a rebar or pipe driven flush into the ground.

Three-Wire Levels. Three-wire levels are used when greater accuracy is necessary. Many leveling instruments are equipped with three horizontal crosshairs. The top and bottom crosshairs are often called ***stadia hairs*** (or ***wires***). The middle hair, at the center of the scope, represents the horizon line of the instrument. On most internal focusing instruments, the spacing of the stadia hairs creates a proportion of 1 foot to each 1⁄100 foot intercepted on the rod. In three-wire levels, the rod is read at each intercept: top stadia hair, middle crosshair, and bottom stadia hair. The readings are made to the thousandth of a foot by visually dividing a hundredth on the rod into 10 parts. The readings are added together and divided by 3 to obtain the mean value. The mean should equal the middle crosshair reading or be within 1⁄1000 foot difference to be valid. Good results may be obtained if only the first section of the rod is used (due to possible movement in the rod section clamps), each shot is balanced, and the distance from level to rod does not exceed 80 feet. The notes are kept in the same fashion as for differential leveling. (See Figure 33.8.)

Note Keeping

Note keeping is a vital component of the survey crew's work. A set of field notes record the date, the crew's identity, and the work performed. Depending on the purpose of the survey, the information and data may be used by designers, engineers, contractors, and other surveyors.

As-built locations, profiles, and topographical survey notes provide designers and engineers with three-dimensional descriptions of existing terrain and features. Stakeout level notes and location survey sketches supply contractors and surveyors with the horizontal and vertical data necessary to create an accurate cutsheet. Sketches of traverse and centerline street references and temporary benchmark (TBM) notes may furnish the starting point for many of the subsequent surveys.

Field note keepers function as the eyes for office personnel; their accurate sketches and observations convey vital horizontal, vertical, and other descriptive material. Moreover, these notes should provide the survey office with the means to check the accuracy of fieldwork before structures are built.

Good notes should be clear, complete, and self-explanatory. Proper notation should be used, along with

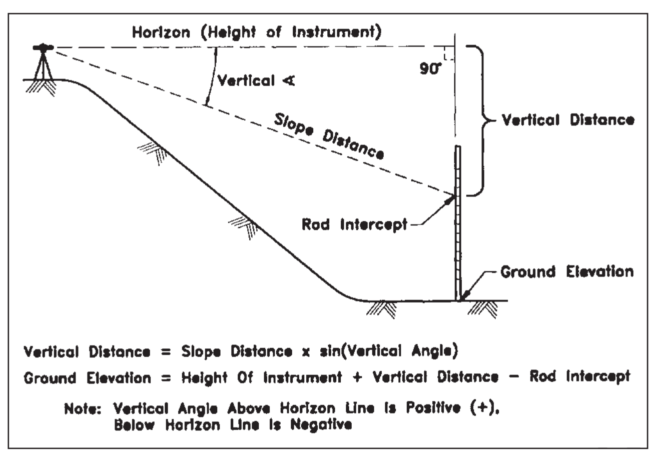


FIGURE 33.4 Trigonometric leveling.

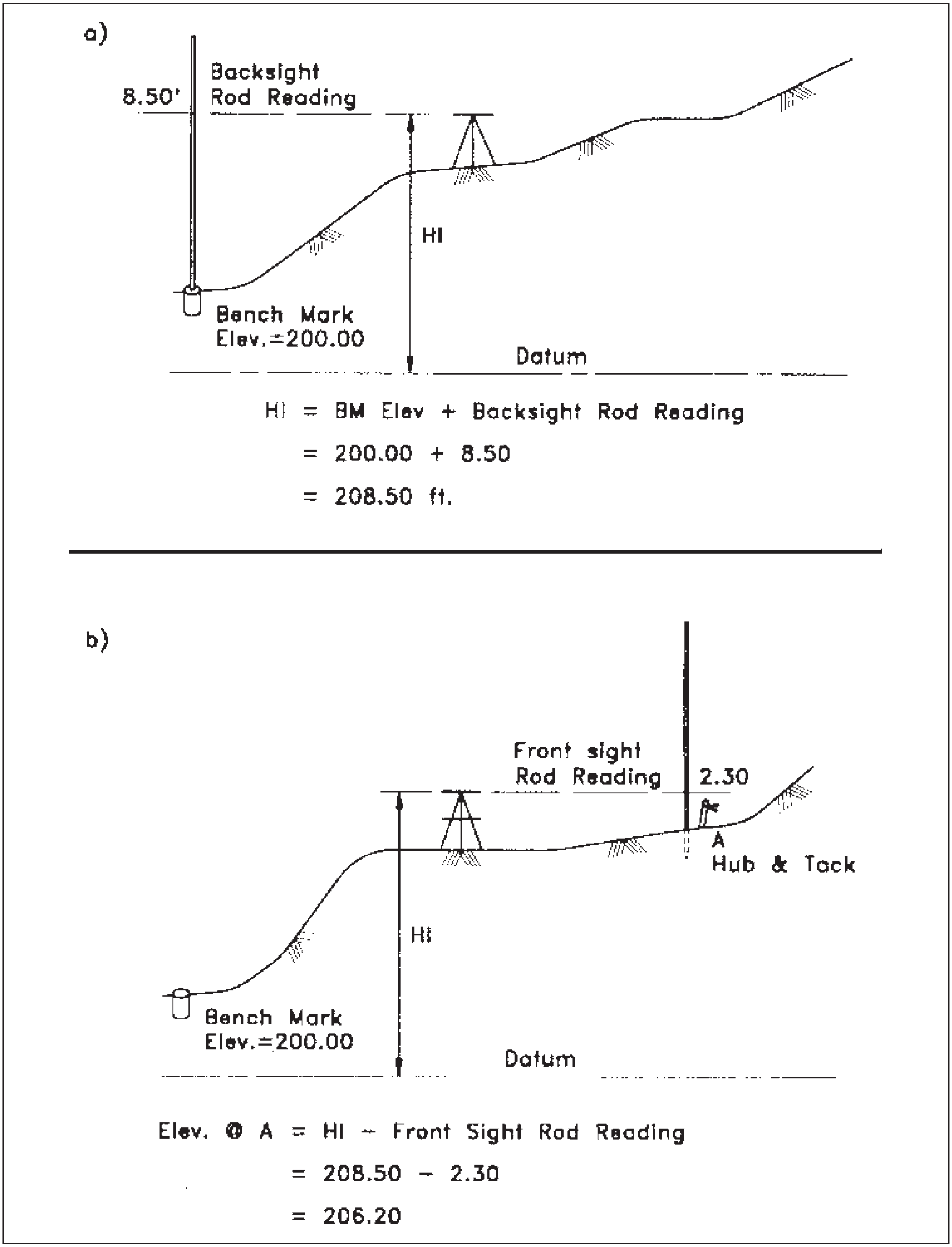


FIGURE 33.5 (*a*) Establishing height of instrument and (*b*) determining elevation.

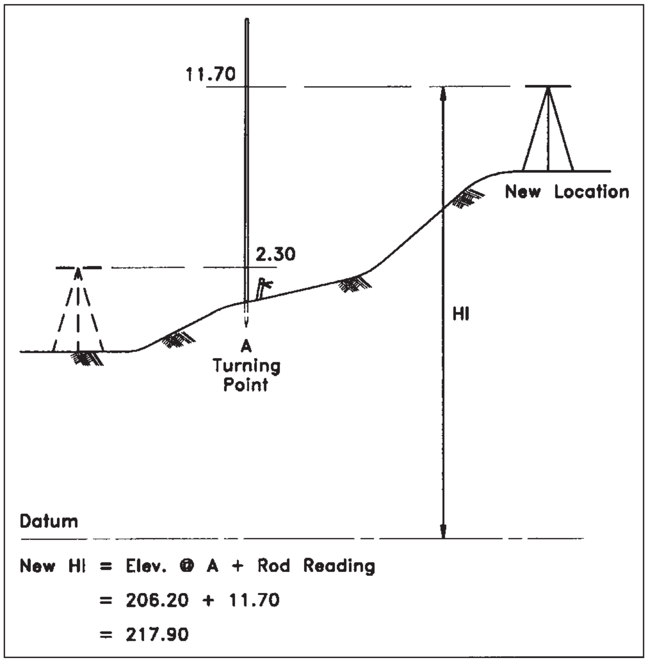
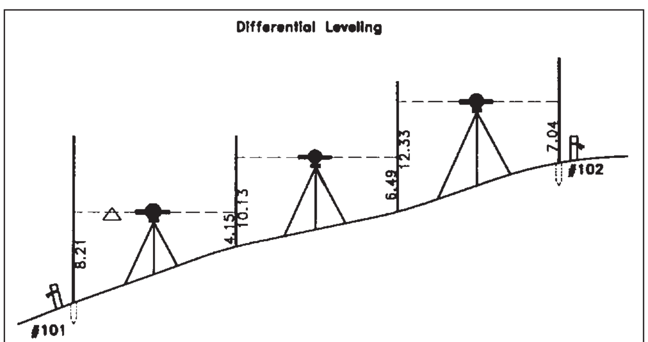


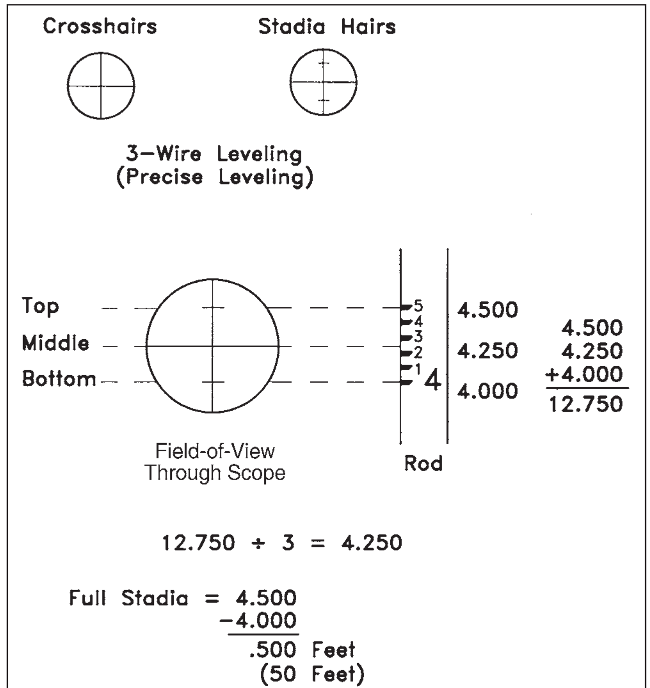
FIGURE 33.6 Establishing HI at a turn.

terminology and symbols standard to the profession. Sketches can convey a great deal of information if they are organized and show all pertinent measurements and observations. An important aspect of a construction stakeout is keeping good records of the work performed. Surveyors must always be prepared to defend their work in this litigious world, and proper documentation is the key. As stakeout markers are easily and frequently disturbed or accidentally removed, records of notes and drawings of the work performed make it easier to reproduce the lost positions and resolve any discrepancies during and after construction.



Station	(+)	H.I.	(−)	Elev.	Grade
TBM: △#101	8.21	358.21			350.00
TP			4.15	354.06	
	10.13	364.19			
TP			6.49	357.70	
	12.33	370.03			
△#102			7.04	362.99 (Error = 0.01)	363.00

FIGURE 33.7 Field notes.



TBM: △#34					7.991
	4.602				
	3.856				
	3.109				
	3.856	11.847			
SET TBM#2			6.308		
			5.491		
			4.673		
			5.491	6.356	
	5.737				
	5.178				
	4.620				
	5.178	11.534			
TBM △#39			2.750		
			2.163		
			1.574		
			2.162	9.372	9.373
				(ER=0.001)	

FIGURE 33.8 Three-wire level.

The use of total stations, equipped with data collectors, does not eliminate the need for field notes and sketches. A job-site field book should be maintained for handwritten notes to accompany the digital data. Field sketches could include outlines of buildings and structures, dimensions, measurements, types of materials, pipe sizes, descriptions, data collection point numbers, and other pertinent facts. In the office, handwritten notes and sketches can be scanned from the field book and added to the job-site database along with the raw and adjusted digital data files. (See Figure 33.9.)

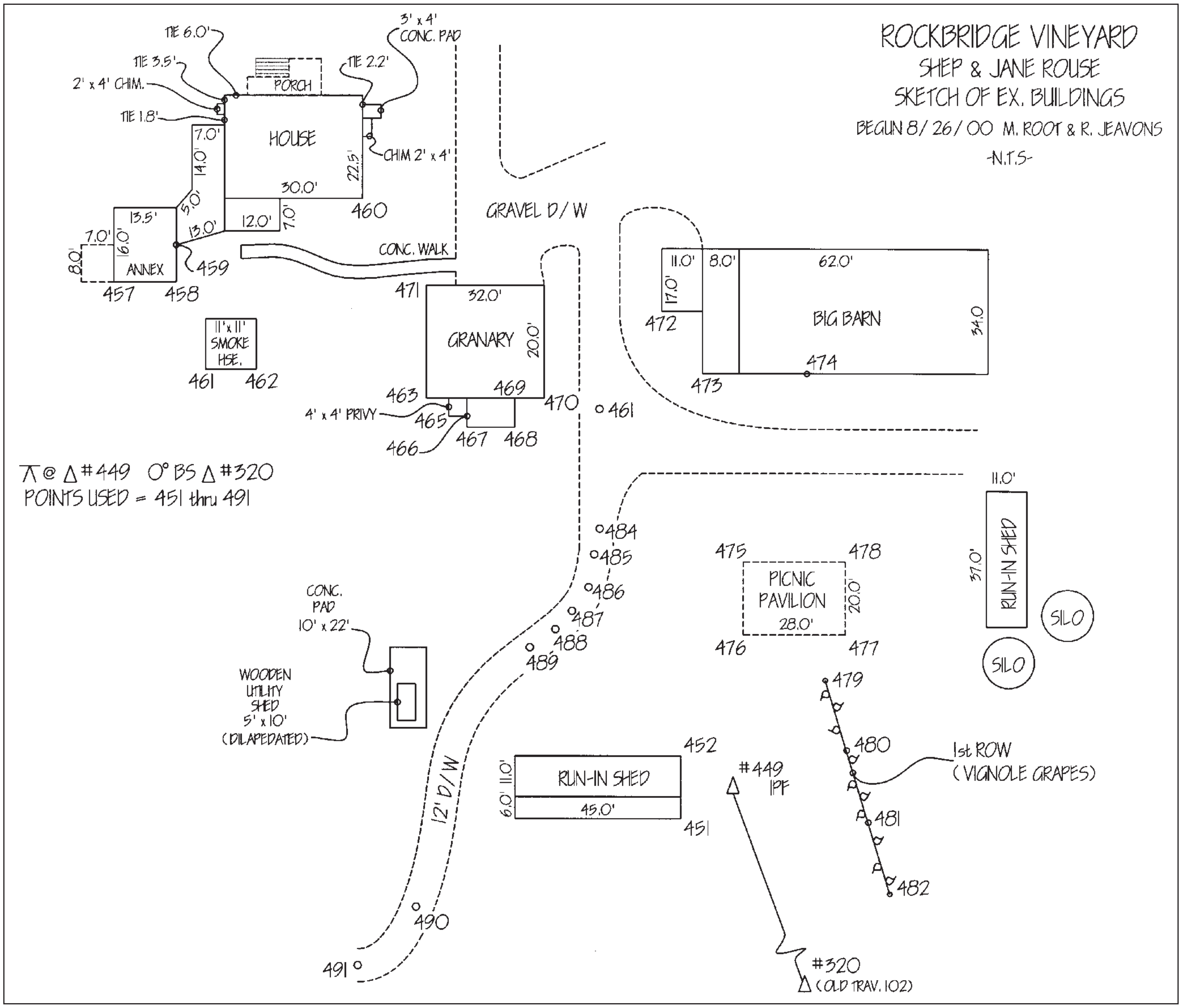


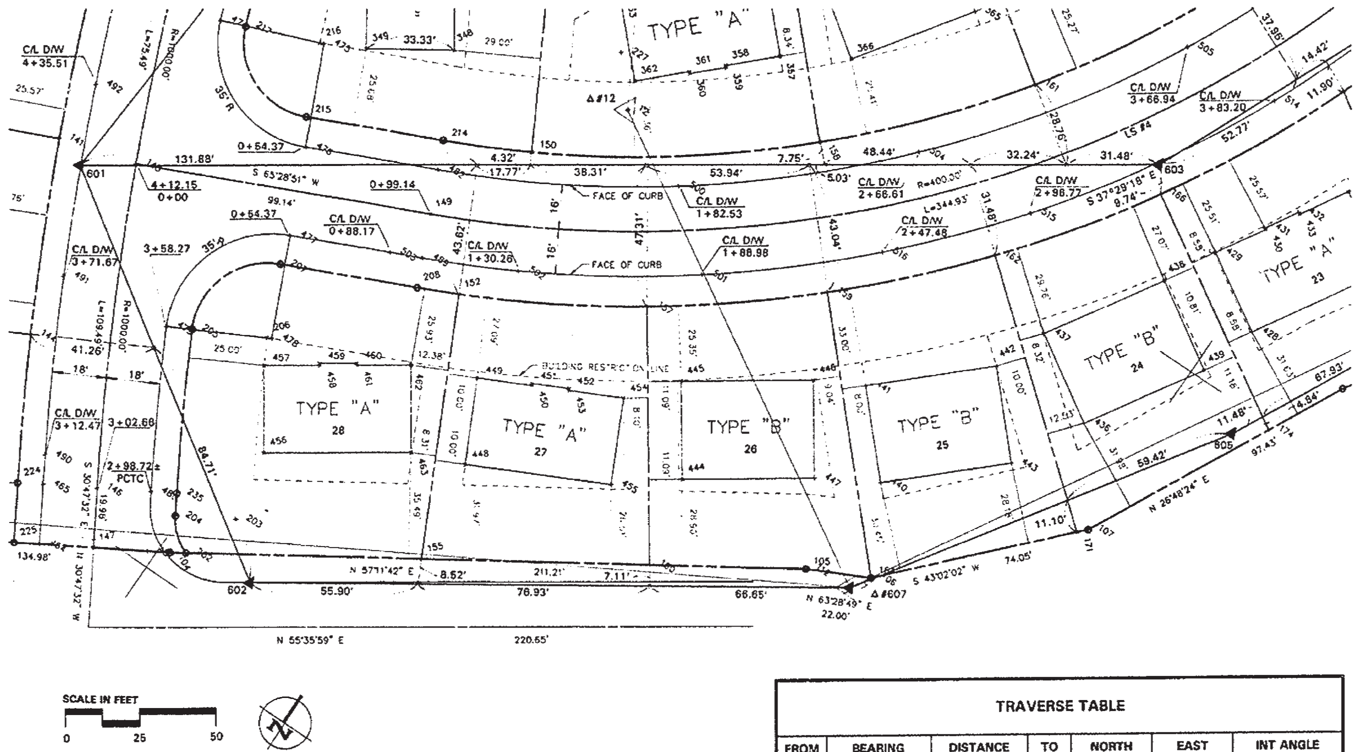
FIGURE 33.9 Field sketch to accompany data collection.

BASIC PROCEDURES

Office Preparations

Office preparation for construction stakeout includes conferring and scheduling with the client, obtaining up-to-the-minute plans, computing necessary stakeout points, drafting the layout, and preparing the job-site folder. The client has specific needs and deadlines, and the field crew's schedules must be organized accordingly with the parameters of the work understood by all. The need for special surveys, such as blasting stakeouts, burn or borrow pit stakeouts, grid stakeouts, or multiple offsets, is dictated by the terrain of the site, the local utility requirements and restrictions, the equipment and materials used in construction, and any problems that may be encountered along the way.

Every construction stakeout involves three important sources of information: the surveying layout plan, the record plat, and the approved construction drawings. The surveying layout plan has the boundary, traverse, and other control points plotted on it. When the client calls for a stakeout of the particular item (e.g., sanitary sewer), the pertinent information is transferred from the construction drawings onto the stakeout layout plan. The widespread use of CAD systems makes it very easy to overlay and transfer this information between drawings. Using CAD systems, coordinates of the stakeout points are then computed and shown graphically on the plan. As construction progresses and more stakeout work is requested, new information is added to the hard copy. The original drawing is kept on the office server and is updated with this additional stakeout information. A copy of the layout plan is made to accompany the field crew. The computed coordinates are then loaded into the field crew's data collector. That information then allows the field crew to perform the stakeout using the total station or GPS. (See Figure 33.10.)



TRAVERSE TABLE

FROM	BEARING	DISTANCE	TO	NORTH	EAST	INT ANGLE
			10	2569.2254	1689.3153	
10	N73°20'40.7"E	245.5833'	230	2639.6131	1924.5954	69°38'56.2"
230	S03°41'44.5"W	291.7350'	601	2348.4848	1905.7910	308°05'30.4"
601	N55°36'14.1"E	359.0948'	603	2551.3412	2202.0989	211°37'38.3"
603	N23°58'35.9"E	308.4006'	604	2833.1303	2327.4217	169°15'23.2"
604	N34°43'12.8"E	201.1012'	554	2998.4241	2441.9629	35°05'08.3"
554	S00°21'55.4"E	172.0513'	606	2826.3762	2443.0601	152°47'57.0"
606	S26°50'07.6"W	376.3439'	605	2490.5620	2273.1674	173°12'26.7"
605	S33°37'40.9"W	137.6367'	607	2375.9568	2196.9443	157°26'52.2"
607	S56°10'48.8"W	199.4823'	602	2264.9304	2031.2159	112°30'35.5"
602	N56°19'46.7"W	150.7075'	601	2348.4848	1905.7910	168°06'41.3"
601	N44°26'28.0"W	309.1733'	10	2569.2254	1689.3153	62°12'51.4"

Figure 33.10 Surveying layout plan.

The plat of record contains bearings, distances, restrictions, notes, easements, curve information, and approvals of the subdivision or individual tract of land. The construction drawings impart details necessary to the proposed construction. A typical set includes an index, a legend of symbols, typical street cross sections, site plans and typical layouts, sanitary plans and profiles, storm sewer computations and profiles, waterline profiles, and street plans and profiles, all of which are vital to the survey stakeout team. The surveyors have the opportunity to recognize any problems, or potential problems, between design concepts and actual construction methods as the layout plan and stakeout ties are produced in the office. When necessary, a solution can be determined in conference with the site design engineers, local government officials, and the client.

Field Procedures

On-site, the survey party will do a reconnaissance of the area, looking for the traverse stations, property corners, and any other known horizontal control points. A minimum of two positions must be intervisible (have an uninterrupted line of sight between each other) in order to begin the survey, so that the instrument can occupy one and backsight the other. Other control points must be recovered to check the work. As the instrument is set up at new positions, it is recommended that an angle and distance be measured to a known control point to verify field computations.

The backsight serves to orient the surveying instrument and provide a basis for determining angular measurements. A predetermined azimuth is established between the instrument's station and the backsight station, which enables the instrument operator to execute new angular directions. A late-model geodetic surveying instrument is capable of turning an angle to the nearest tenth of a second, but for most construction layout purposes, a 20-second instrument is adequate. (Note that trigonometrically, 20 seconds of angular error projected to a distance of 100 feet yields only 0.01 feet of error, a displacement well within the acceptable limits for almost all types of construction. There are methods that, when applied, can further refine the accuracy of a 20-inch second instrument). Advancements in electronic technology will undoubtedly make total stations and data collectors more affordable and more precise, rendering conventional surveying instruments virtually obsolete.

The most common method of distance measurement in construction stakeout is the total station. The total station is one of the fastest and most accurate methods for determining distance, although GPS is quickly replacing total station use and is especially beneficial when stations are not intervisible. Past methods of distance measurement include pacing, chaining, and taping. These older methods are still used to locate property corners, traverse stations, and other points of interest during site reconnaissance.

After a reconnaissance is complete, the party chief must form a logical sequence for the survey, based on the points recovered, stakeout desired, on-site obstacles, and the distances involved. While a timely survey is desirable, accuracy is a necessity. The party chief should have a firm grasp of trigonometry and coordinate geometry because of the number of computations that are often solved in the field, such as inverses using coordinates or bearings and distances, and intersections using bearings and/or distances. This knowledge is necessary to troubleshoot possible problems in the plans, create alternative ways to perform a survey, and provide mathematical checks on and corrections to work in progress. Data collectors are invaluable in aiding the party chief with these calculations.

First and foremost is the need to check the work completely. There are routine checks in mathematical computations and there are routine checks in laying out and staking. A minimum of three control stations are needed to lay out and check a survey. Ideally, the instrument occupies one control station, while another control station is sighted. Then the surveyors measure a computed angle and distance to the beginning point of the stakeout. The instrument is moved ahead to the new point, the last station occupied is backsighted, and a new angle and distance are measured, this time to a third control station. If this checks, then the accuracy of the beginning point is established. For a lengthy stakeout, the instrument is moved forward to each subsequently set point, backsighting the last, so that the whole series is proven to a known control station at the final check-in.

Using Total Stations and Data Collectors for Stakeout

The data collector is capable of storing a job site's entire coordinate geometry file. These electronic field books store and collect data and interface directly with a total station instrument and a computer. With this information, the data collector computes coordinates from distances and angles and vice versa; performs inverses, intersections, and resections; and determines stationing and offset positions, elevations, and cuts and fills. The computed information can be stored for field or office reference and record-keeping purposes.

In the office, up-to-date plans are assembled, coordinates are generated, and plots are created showing the stakeout points overlaid on the construction plans. The data is loaded into the data collector and readied for the field. In the field, the station occupied, height of instrument, elevation of station, and backsight and foresight information are entered into the data collector. Once this is accomplished, the actual backsight and foresight are taken, using the total station and a prism target. The data collector can determine the horizontal and vertical position of the occupied station for comparison and check. Once the occupied position is verified, the radial stakeout can commence.

A *radial stakeout* is a method where many or all offset points are established from one instrument setup. This method is best when used with a total station and data collector. To the novice surveyor, this method can look like one big game of guess and check. The prism handler walks to the spot where he or she thinks the stake will be and the instrument operator locates the prism. The data collector then compares the coordinates of that location with the computed coordinates provided by the office personnel who prepared the stakeout work. The instrument operator then interprets this comparison and instructs the prism handler how to adjust the prism position to obtain the desired location. Commands such as "in," "out," "left," and "right" are typically given from the prism handler's perspective. For example: "Come in 2.45 feet and right 0.89 feet." The prism handler would then walk toward, or closer to, the total station 2.45 feet and then shift to his or her right 0.89 feet. The process is then repeated until the prism is within specification. The hub or nail is then driven into the ground and another, final, location is taken and stored in the data collector. This saved location provides evidence that the point was indeed staked and that it was within specification, and, perhaps more important, it provides a vertical elevation on the hub to be used in a cutsheet.

However, a radial stakeout can be risky if not followed with a series of checks. Before the stakeout begins, the party chief should compare information from the plans and profiles with information computed by the data collector. Using the feature that computes inverses between points, the party chief checks street widths, offset lengths, distances between structures, and building dimensions. As the stakeout progresses, the backsight should be checked periodically, and before moving the instrument to a new location, to ensure the accuracy of the instrument's orientation. Good communication between the instrument operator and the prism handler should be maintained to ensure accurate entry of prism height for each instrument reading. Wherever possible, angles and distances to other known control points should be made from the key points of the stakeout. Distances between offsets and the centerline of the stakeout can be quickly checked by taping. Finally, a location of key stakeout points should be made from a known control point that was not used as part of the survey. This provides verification and a record of the points staked.

Back in the office, the data is downloaded into a computer. It is recommended that no more than one day's worth of work be allowed to accumulate in the data collector. The party chief is consulted for the initial edit of the data file, where errors in coding, prism height, backsight, or foresight entry can be corrected. After the data is downloaded into a computer, plottings can be made of the work.

Errors in Stakeout Surveys

There will always be a certain amount of error in a stakeout due to weather, equipment, terrain, and human fallibility. A survey party chief knows the tolerances of acceptable error. Stakes that are set for controlling earthwork activities need only be within 1 foot horizontally of the plan location, whereas stakes set for house construction must be accurate to the nearest hundredth of a foot. Each type of stakeout must be analyzed in light of its purpose, how it will be used, and whether these points can be used for another survey. With this knowledge, the amount of tolerable error can be determined, and if it is exceeded, the source of the error must be found and corrected.

After the stakeout is complete, the survey crew should step back and look at the big picture of the stakeout. Too often, the same attention to details and intricacies and the level of effort used to set individual points is not given to the overall task. Taking time to view the stakeout from a farther or different vantage point or comparing it to the construction drawings may disclose an obvious error or blunder. The cost of this short amount of time is inconsequential when compared to the cost of re-staking, reconstructing, or replacing dirt, concrete, and asphalt.

Cutsheets

The cutsheet is a method for organizing and presenting stakeout calculations. For surveyors, it is a record of what was done in the field. However, contractors use it to establish line and grade for buildings and trenches, while municipalities may require it as part of the permit/inspections process. A typical cutsheet form is shown in Figure 33.11. Specific cutsheets can be tailored for a particular type of stakeout.

After the stakeout and elevations for the hubs have been established, the field notes and construction drawings are used to fill out the cutsheet. The column labeled "STAKE EL." represents the offset hub elevation as determined in the field; "GRADE EL." is the proposed elevation of the pipe invert, manhole rim, storm grate, building floor elevation, top of curb, or any other desired point of interest. This elevation is taken from the plan or profile of the construction drawings. The difference between these two values is the amount of cut or fill.

Proposed grades for gravity flows are computed using the invert elevations and the slope of the pipe. Elevations to inverts for pipes carrying pressure flows are scaled from the profile or computed based on the finished grade elevation and the minimum cover to the pipe. In street and parking areas, the top-of-curb elevation or edge of pavement is typically used in the cutsheet calculations. Top-of-curb elevations in streets are easily determined from the longitudinal grades and the typical section of the street. However, computing top-of-curb elevations in parking areas is not as straightforward. Because parking pavements have variable and nonuniform longitudinal slopes and cross slopes, the proposed elevations are computed from given spot elevations or by using judgment. When the plan is too vague to determine a workable elevation, the surveyor should immediately consult with the design engineer.

The cutsheet is one of the last points in the design process where errors and conflicts can be caught before they become costly to rectify. The individual computing the cutsheet should watch for conflicts where pipe and other utility crossings occur, check to see that minimum depths are adhered to, and be attentive to other possible engineering, field, and construction conflicts. The contractor needs

County #: ____________________ Plan #: ____________________

Project : ____________________ **Grade to:** ____________________

Prepared by : ____________________ **Date:** ________ ____________________

Staked by : ____________________ **Date:** ________

Dewberry & Davis

Architects
Engineers
Planners
Surveyors

8401 Arlington Boulevard
Fairfax, VA 22031-4666
703/849-0229 Tel
703/849-0118 Fax

DESCRIPTION	OFFSET	STATION	STAKE EL.	GRADE EL.	CUT/FILL	REMARKS

FIGURE 33.11 Typical cutsheet.

the cutsheet information to begin construction. Typically, it should take less than a day or two from the completion of the field stakeout to prepare the cutsheet and return it to the contractor.

Descriptions and examples of cutsheets for particular stakeouts can be found throughout this chapter.

CLEARING STAKEOUT

On a wooded site, the first stakeout usually requested establishes the clearing limits. Trees enhance a property's value, and parcels with stands of trees often command higher prices. Contracts may be lost and lawsuits filed if the wrong trees are removed during the clearing phase of construction. The site plan shows the limits of clearing, and it is important to adhere to this limit line with little deviation. Allowing too many trees to be removed may create erosion and runoff problems and may violate local arboreal regulations, resulting in fines and/or mandated replacement of the lost trees. Conversely, allowing too few trees to be removed results in a costly and time-consuming rescheduling of tree removal equipment, thus delaying other construction activities.

Presently, most clearing stakeouts are performed using a total station and prism pole, with a data collector. On fully wooded sites, GPS is undesirable because the tree canopy blocks the signal and significantly degrades the survey accuracy. The only opportunity to use GPS for a clearing stakeout would be a partially wooded site during winter months when the trees lack leaves. The lack of leaves could allow enough of the GPS signal through to obtain the desired accuracies.

Coordinates are computed for points along the clearing line, and the data is uploaded into the data collector. In the field, the data collector provides the angles and distances from the occupied station to any point desired. The points that are actually set can be located and stored in the data collector and plotted in the office later, serving as a check of the work.

In the field, control points are recovered and referenced if they appear threatened by the clearing operation. As each point of the clearing limit is established, the rod person ties a streamer of flagging before moving on to the next logical point. The person at the instrument must make certain that the points are spaced at intervals so as to be intervisible through the woods and to guard against the loss of accuracy caused by spacing the tie points too far apart in a curve (following a chord instead of an arc). After the key points are set, they are connected by running flagging between them. It is tied high and secured well so it will remain undisturbed by the weather and out of reach of any children who might wander onto the site. In areas where vandalism might be a problem, the contractor may request that the trees be marked with paint as well. Flagged trees along a limit line are left standing, a fact that must be considered before tying or painting a dead or damaged tree.

The party chief makes sure there is sufficient width flagged on the utility easements to accommodate the depth of the trench and working room for the machines. In addition, the party chief may decide to flag a slightly larger area if the clearing limits seem tight in relationship to the proposed buildings. Finally, the party chief should locate any specimen or monarch tree that may be a borderline case for removal. In an effort to save such a tree, the field location notes are plotted by the survey office personnel and sent to the planners and engineers to make a determination.

If rights-of-way or easements alone are requested for a clearing stakeout, another procedure can be used. The centerline of the street, right-of-way, or easement is staked every 50 or 100 feet. Again, it is good practice to measure an angle and distance to a known control point to verify the stakeout. Once this is accomplished, distances to the clearing limits can be measured from right and left of the centerline points.

GRADING

Street Grading

The centerlines of streets are generally used to control the horizontal and vertical limits of their construction. For subdivision streets, the stakeout consists of setting hubs at the centerline's main points such as points of curvature (PCs) and points of tangency (PTs), and at 50-foot intervals. As a check, ties (measuring angles and distances) are made to control points from selected PCs and PTs. The ties are made when control points can be sighted and measured without too much difficulty from the selected points on the centerline. However, it is a rare situation when ties can be made frequently as the stakeout progresses. Typically, early control points are near the project's boundaries. Therefore, ties are made as the street stakeout nears the boundaries.

The outside limits of the grading for the street can then be established by measuring the necessary distance, radially or perpendicular, from the centerline hubs. In most cases, the horizontal accuracy required for setting the outside limits for the rough grading is approximately 0.5 foot. The stakeout for the street is set on the actual centerline rather than offset. Although this might obstruct the equipment operators as they grade around these points, the close proximity of the points allows the contractor to accurately set the street grades even in the rough grading phase. Evidence of the saved points within the grading area are apparent on construction sites where one can see numerous nearly cylindrical mounds with guard stakes and surveyor's flagging on top. When the street is brought to grade, these mounds are easily removed.

Elevations are determined for all the hubs, starting at the point where the street construction is to begin. On most projects, street construction begins where the intersection of the proposed street meets an existing street near the boundary of the site. From here, the construction proceeds toward the interior of the project. In addition to providing a beginning point where the elevation of the proposed street is assured of matching the elevation of the existing street, this practice provides a logical order for surveyors to check the work against the plans and supplies the contractor with a cutsheet starting at the most accessible beginning point. If the cutsheet provides cut and fill depths to the finish grade of the street, the contractor is responsible for deriving the subbase elevations.

Slope Staking

Engineering projects such as road and rail beds, ditches, and canals often use slope stakes to define the limits of excavation and grading. The slope stake is referenced to as the *catch point;* the intercept is where the finished side slope meets the original ground surface. Slope stakes are especially helpful to the contractor in areas of cut, where the catch point is less apparent than in areas of fill.

To begin the survey, the centerline of the road or ditch is staked at regular intervals and elevations are determined at each station. The next portion of the survey, setting the slope stakes for each station, uses a level, a leveling rod, and a measuring tape. The objective is to find the catch point left and right of each station, which is achieved by using Equation 33.1 and a series of trials:

$$d = \frac{w}{2} + hs \tag{33.12}$$

Here, ***d*** is the measured horizontal distance from centerline to the catch point, ***w*** is the plan width of the roadbed or ditch, ***h*** is the cut or fill at the centerline, and ***s*** is the side slope ratio. These parameters are shown in Figure 33.12. As shown, the inherent horizontal error in Equation 33.1 is due to the variation in depth ***h*** at the centerline and the actual depth at the catch points h_L and h_R. For this reason, setting slope stakes in the field becomes a trial-and-error process.

To begin the process, the level is positioned and an HI established by taking a rod reading on the centerline station previously established. From the plans, the final road grade elevations along the centerline and the typical cross-section side slopes are extracted for the calculations. The difference between the HI and the finished grade elevation is known as the ***grade rod.*** The difference between the rod reading at a trial location and the HI is known as the ***ground rod.*** The ground rod is variable and depends on the trial location, whereas the grade rod is constant for a given centerline station. The cut or fill at any trial point in the section is figured by subtracting the ground rod from the grade rod. The equation can then be expressed as:

$$d = \frac{w}{2} + s(\text{grade rod} - \text{ground rod}) \tag{33.2}$$

The objective in the field is to find a ground rod such that the right side of Equation 33.2 is equal to the distance from the centerline at the location of the rod reading.

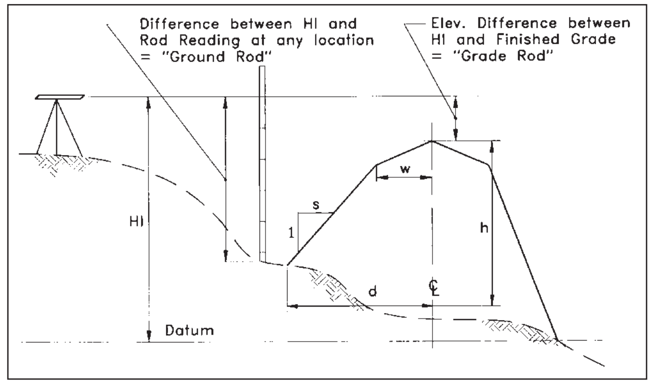


FIGURE 33.12 Slope staking.

EXAMPLE

In this example, the road width is 24 feet, the side slope ratio is 2:1, the finished grade elevation at the centerline is 29.0 feet, and the HI is at elevation 42.0 feet.

(1) The grade rod is 42.0 feet − 29.0 feet = 13.0 feet. Using Equation 33.1, the first trial distance from the centerline is 38 feet.

$$d = \frac{24}{2} + 2(13) = 38 \text{ ft} \tag{33.3}$$

At a trial distance of 38 feet, the rod reading is 4.2.

$$38 = 12 + 2(13.0 - 4.2) \tag{33.4}$$

(2) Use this information and Equation 33.2 to see if the right side of the equation balances the left. Obviously 38 feet ≠ 29.6 feet. The left side of the equation must decrease and the right side must increase, so the rod person is directed downslope, or closer to the centerline.

(3) The second trial, at 29.6 feet from centerline, yields a rod reading of 4.3, which, when placed in the equation, shows 29.6 = 12 + 2 (13.0 − 4.3), producing a value of 29.4 feet for the right side of the equation (29.6 ≠ 29.4).

(4) Moving the rod to a location of 29.5 feet from the centerline produces a ground rod of 4.3 feet. This final trial yields 29.5 = 12 + 2 (13.0 − 4.3), thus 29.5 ≈ 29.4. This is within 0.1 foot of where the rod is being held, so the catch point is recorded at 29.5 feet from the centerline and the depth of cut is recorded as 8.7 feet (13.0 − 4.3). The catch point is then offset, away from centerline, and the stake is marked to express the information to the contractor. The front of the stake indicates the offset distance to the catch point, the cut or fill from the catch point to the finished centerline grade, and the station. The back of the stake indicates the offset distance to the centerline and the cut or fill from the offset elevation to the finished centerline grade. (See Figure 33.13.)

Construction plans for many subdivision streets contain a contour grading plan or street cross sections. If the topographic maps used to create these are reasonably accurate, the catch points can be computed directly from these drawings.

Overlot Grading Stakeout

On many well-designed projects the earthwork balances; that is, the volume of cut equals the volume of fill (see Chapter 23). However, in many projects the cut areas are a considerable distance from the fill areas. Consequently, the dirt must be hauled from one place on the site to the other. Overlot grading is one phase of grading where the site is mass graded to bring the entire sight closer to the finished grade.

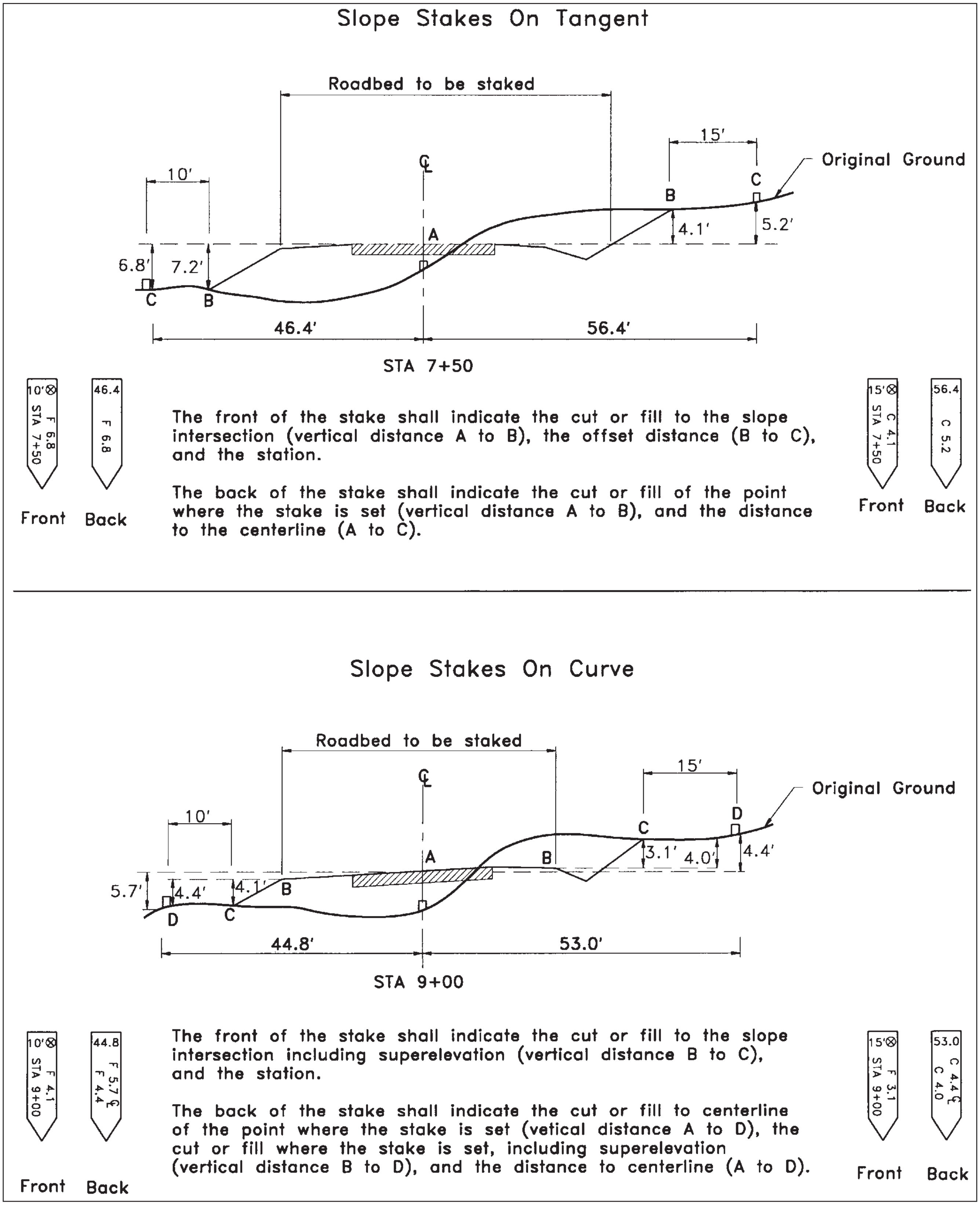


FIGURE 33.13 Setting and marking slope stakes. (Courtesy of Virginia Department of Transportation, Location & Design Division, *Survey Manual 1991*)

In residential developments this usually includes transporting dirt from one lot to another lot to minimize grading operations during house construction. Typically, such grading operations are associated with commercial and high-density residential developments.

For projects that require a large amount of earthwork, an overlot grading stakeout may be requested. Overlot grading can be accomplished with a grid stakeout or a contour stakeout. The need dictates the means.

Grid Stakeouts. Grid stakeouts are performed when the earth base must be relatively accurate. To ensure a reasonable degree of accuracy, the grid points are usually staked at a close interval. Depending on the size of the project, 25- to 100-foot grid intervals can be used, and cuts and/or fills are determined for each gridpoint. When establishing the grid in the field, a matrix numbering system helps identify each grid point. One method is to label each grid intersection with a number and a letter: the number represents the line in one direction, and the letter represents a line perpendicular to it. This identification is written on a stake and placed at the intersection of the two lines. The grid is superimposed atop the grading or site plan. The amount of cut or fill is determined from the difference between the existing and the proposed grade at each grid point. The grid-point elevations are interpolated between contours, spot elevations, or building corner grades. A copy of the grid layout is furnished to the contractor along with the cutsheet.

Contour Stakeouts. Contour stakeouts are typically used for ponds, berms, and slopes. A contour stakeout transfers selected contour lines from the plan to the field to guide the earthmoving operations. The key points to be staked are computed using CAD to determine the coordinates. When selecting these points, their spacing and location must take into account the maneuverability of the grading equipment. The stakeout markers should be highly visible to the equipment operators, sometimes necessitating the use of 4-foot-tall stakes to guard the hubs. Tall stakes also provide ample room for cut, fill, and grade markings; the proposed contour; and the elevation of the hub.

The stakeout can be achieved with a total station/data collection system. After the hubs are set, elevations are obtained and a formal cutsheet is issued, supplying the cuts and fill information.

SANITARY SEWER STAKEOUT

The design, construction, and operation of the sanitary sewer are based on the invert elevations of the pipe. A manhole is constructed at each horizontal change of direction or vertical grade break in the pipe. Each manhole, existing and proposed, has a minimum of three important elevations: the top, the invert elevation(s) of inflow pipe(s), and the invert elevation of the outflow pipe. A manhole structure may be located according to the centerline of the barrel or the centerline of the cover. Some types of manholes are built with the centerline of the cover offset from the centerline of the main barrel, which may be 1 to 2 feet. The point used to locate the manhole depends on the purpose and intent of the survey. For as-built surveys and construction purposes, the center of the barrel structure is crucial to pipe slope, pipe length, and easement calculations. For topographic surveys, the center of the manhole cover is often sufficient.

The construction drawings and the record plat contain the information pertinent to the stakeout preparation. Bearings, distances, and widths of easements are shown on the record plat and plotted onto the stakeout hard copy. Office personnel compute the offsets (typically 20 feet) and provide the field crews with coordinate data. Field crews are then able to perform the stakeout using total station and GPS methods.

The stakeout proceeds in the direction opposite that of the proposed flow, that is, upstream. The backhoe begins at the lowest point of the stakeout, usually an existing manhole, and digs progressively up the line, "out" of the lower manhole "into" the higher manhole. The lowest manhole invert of the line to be staked is the beginning, its offset hub is called the OUT, and its station designation is typically 0+00. If the length of the sanitary line to the next manhole is 100 feet, then the offset station for that manhole is 1+00 and is called the IN. Another hub is set for this same manhole and designated as the OUT. This hub is 90 degrees from the bearing of the pipeline entering the manhole. At this hub the stationing reverts back to 0+00 again before proceeding to the next manhole. In this manner, the actual distances between manholes are self-evident and can be readily compared to the construction plan, the stakes, and the cutsheet pluses.

Intermediate stations are staked and the stakeout length is checked for compatibility with the profile (see Figure 33.14). The offset line stations between the OUT and the IN are generally set every 50 feet, but if the terrain is steep, 25-foot stations may be required to ensure that the pipe crew has enough horizontal and vertical checks as the line progresses.

After the offset hubs are set, the final coordinates of the hub are saved, including elevation data that can be used later in preparation of the cutsheet. The existing manhole where the stakeout began is accurately located, with the top rim used as the principal reference point. The existing pipe inverts are measured down from the top elevation. If the proposed sanitary sewer line is tying into an existing sanitary line between two manholes, both existing manholes must be located vertically and horizontally. The distance between them is measured to determine the slope of the existing pipe. Proration is then used to determine the invert pipe elevation of the new manhole.

Sanitary Sewer Lateral Stakeout

The sanitary sewer lateral is the relatively short length of sewer line that runs from the collector line to the property line. In most municipalities this is considered as part of the

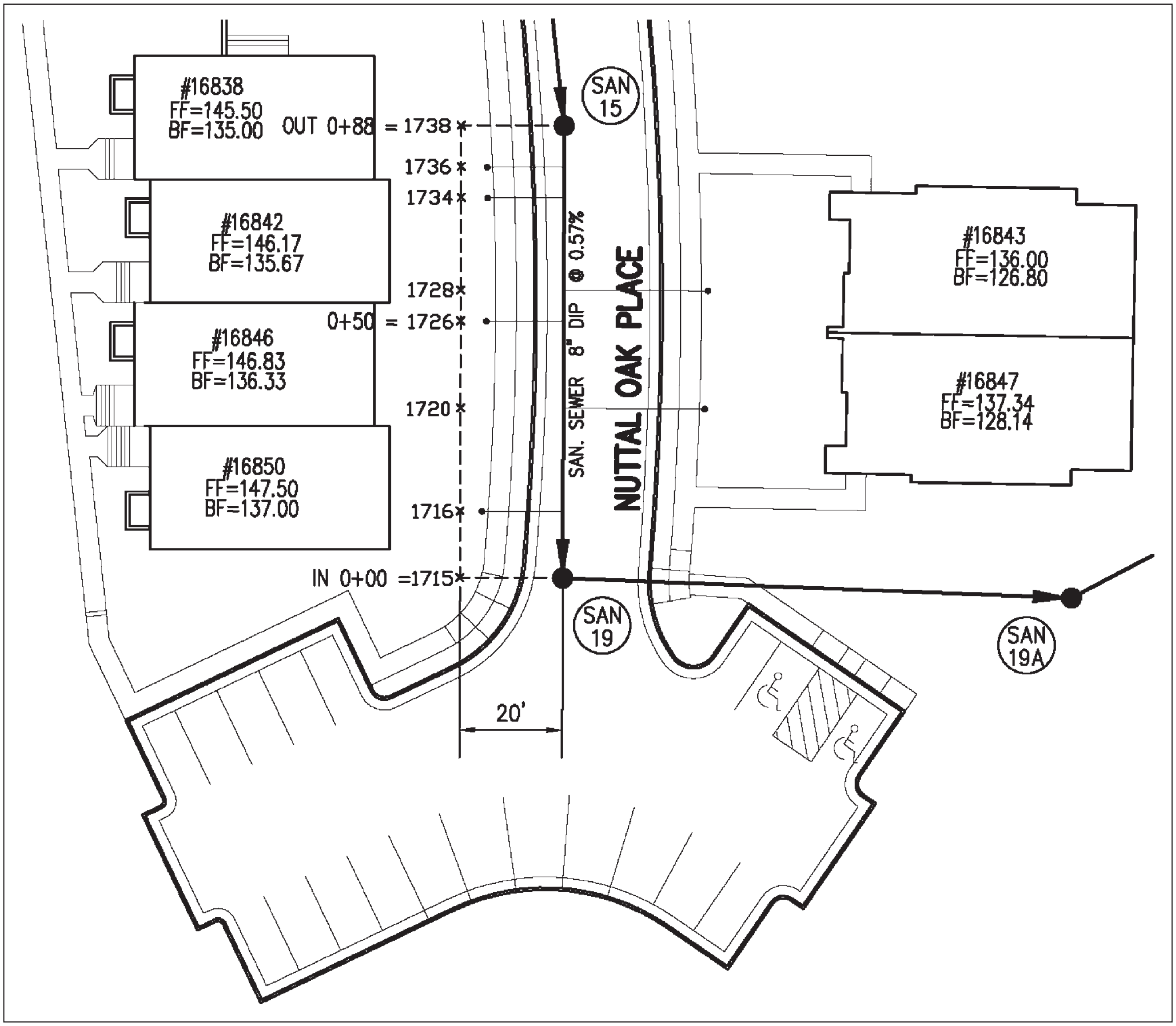


Figure 33.14 Typical sanitary sewer stakeout.

public sewer system; thus, the municipality is responsible for its maintenance and repair. The remaining part of the sanitary line that connects the lateral to the house is considered privately owned, and the maintenance of it is the responsibility of the plumbing contractor doing the pipe work for the building.

Before setting any stakeout hubs, the survey computer compares the location of the lateral, shown on the profile sheet, with the location shown on the plan. Discrepancies are resolved and duly noted, or in extreme situations the engineer is consulted before proceeding with the stakeout. The lateral's length on the plan view is checked by scale, and the presence of risers (vertical pipes) in the lateral section are noted, as these must also be marked with offset hubs. Finally, each lot is checked to ensure that there is a lateral provided.

For each lateral, a hub is placed at the appropriate station along the main section of the sanitary sewer system. The length to the riser, plus the offset distance, is also measured and staked. This method places the stakes on the lateral line extended. Another way to offset the lateral is up the main sanitary line, at the offset distance. Both of these methods are illustrated in Figure 33.15.

Cutsheets for Sanitary Sewers and Sanitary Laterals

After sanitary sewer laterals are staked and the readings verified, cutsheets are prepared from the stakeout information. Before the cutsheet is started, the person preparing the cutsheet checks the field notes and certifies that they are correct by initialing them. If there is an error in the field notes, the party chief is consulted and a site visit may be necessary to resolve any discrepancies.

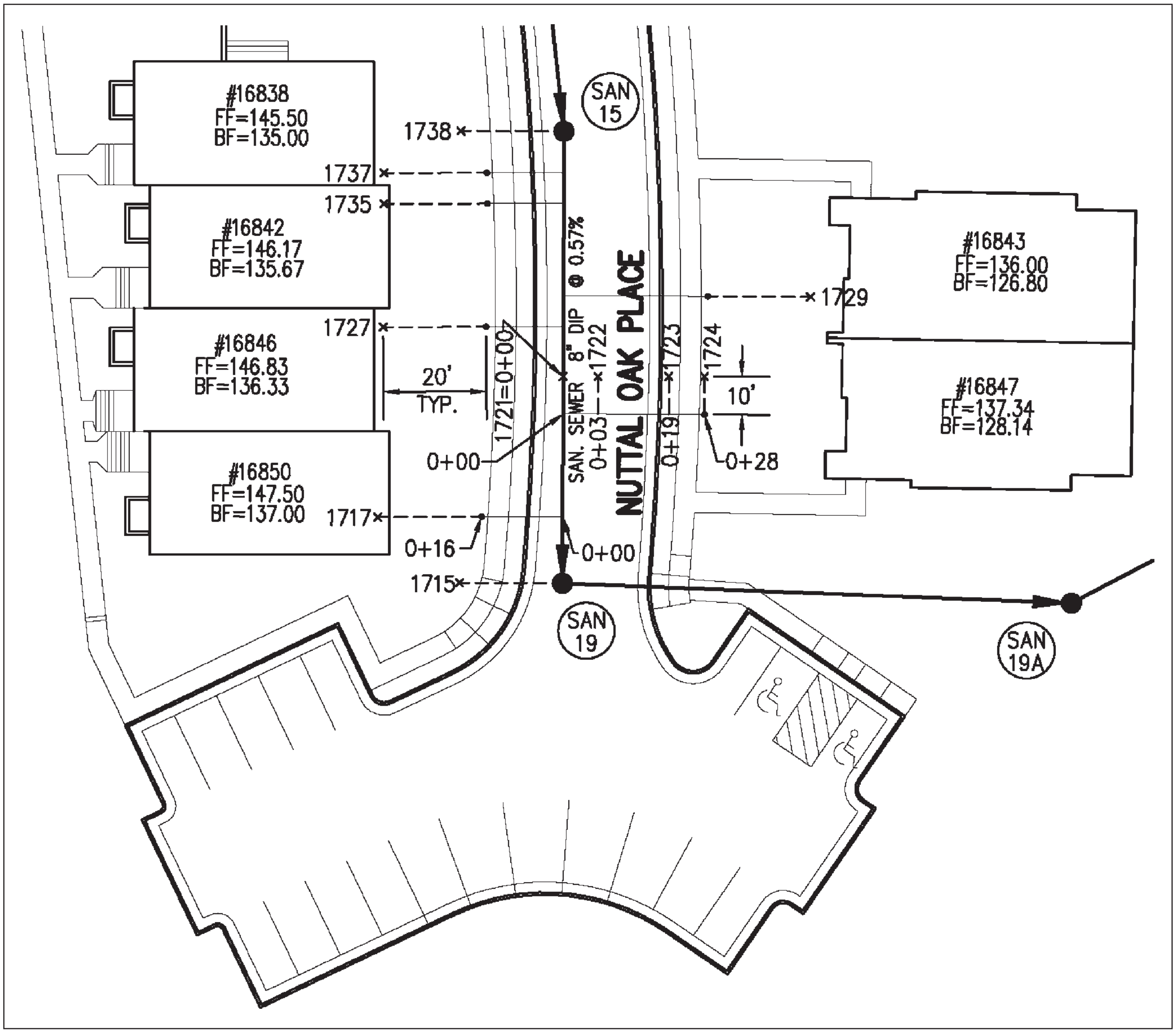


FIGURE 33.15 Sanitary lateral stakeout.

Next, copies of the current profiles, record plat, and surveying hard copy are gathered for reference. The cutsheet is prepared using specialty software or a standard spreadsheet computer program with columns laid out for each piece of information. The heading is filled in with the name of the job site, along with any reference numbers, file numbers pertaining to the construction drawings, the party chief's name, and the cutsheet preparer's name. The manhole designations and stations, with the elevations of each hub, are copied from the field notes and placed in their respective columns. The proposed inverts, taken from the profile sheet, are filled in next, along with the size of pipe. The pipe slope is calculated and compared with the profile, and the remaining inverts are computed. Invert elevations for the house or building laterals are calculated at the mainline, at the riser, and at the end of the lateral.

The vertical difference between the elevation of the hubs and the elevation of the sewer main and laterals are computed for each station and entered in the appropriate column. This vertical difference is the amount of cut that the backhoe will have to excavate to reach the proposed invert elevation. Final checks include scaling the location of the laterals on the plan and profile sheet (see Figure 33.16), and checking the record plat and hard copy to verify that they coincide with the stakeout. Copies of the completed cutsheet are sent to the proper municipal agency, if required, and to the contractor (see Figure 33.17).

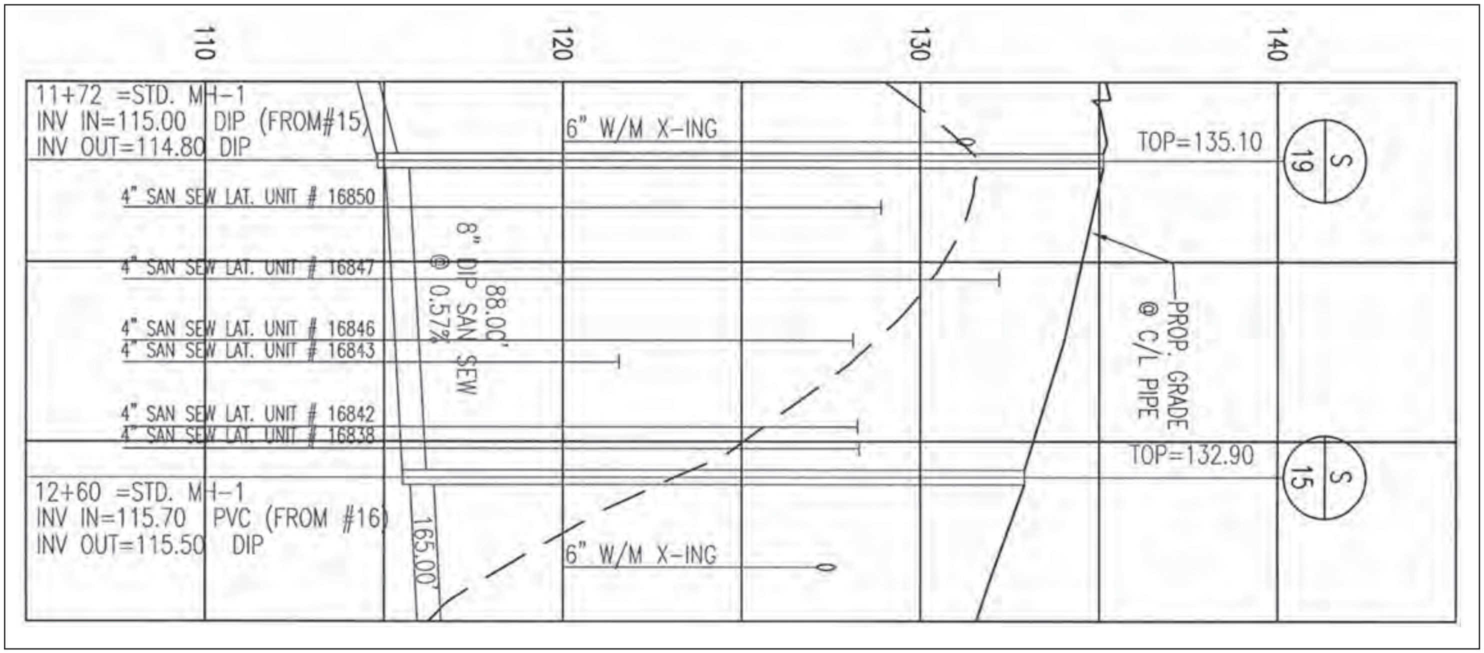


FIGURE 33.16 Sanitary sewer profile.

Dewberry

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Manassas, VA 20109
ph.703 631 3430 fax.703 631 0234 www.dewberry.com

Date:7/7/2006	Job: River Oaks	BENCHMARK:
LOCATION: Structure 19 to 15		PARTY CHIEF: FORD
DESCRIPTION: **Sanitary Sewer**		PREPARED: JAA

Point	Offset	Station	Hub Elev	Prop Elev	Cut	Fill	Remarks
SANITARY SEWER							
							Top of Structure # 19 = 135.10
1715	20' Left	0+00	130.85	115.00	15.85		MH Str # 19 (In) 88.00' 8" DIP @ 0.57%
1716	20' Left	0+13	129.32	115.07	14.25		San Lat Tee - Unit # 16850
1720	20' Left	0+33	128.34	115.19	13.15		San Lat Tee - Unit # 16847
1726	20' Left	0+50	127.22	115.28	11.94		San Lat Tee - Unit # 16846
1728	20' Left	0+56	127.68	115.32	12.36		San Lat Tee - Unit # 16843
1734	20' Left	0+74	125.27	115.42	9.85		San Lat Tee - Unit # 16842
1736	20' Left	0+80	124.28	115.45	8.83		San Lat Tee - Unit 16838
1738	20' Left	0+88	123.95	115.50	8.45		MH Str # 15 (Out)

NOTE: SURVEYOR DOES NOT TAKE THE RESPONSIBILITY FOR ANY ALLEGED ERROR OR DISCREPANCY FOUND IN THE FIELD OR ON THIS CUT SHEET UNLESS DEWBERRY AND DAVIS IS NOTIFIED IMMEDIATELY SO THAT THE MATTER CAN BE CHECKED AND RESOLVED STAKES PLACED IN THE FIELD BY DEWBERRY AND DAVIS MUST BE UNDISTURBED AND IN PLACE SO THEY CAN BE FIELD CHECKED AND VERIFIED. CONTRACTORS MUST CHECK THREE OR MORE HUB ELEVATIONS PRIOR TO THE START OF CONSTRUCTION.

FIGURE 33.17 (*a*) Sanitary sewer, and (*b*) sanitary lateral cutsheet.

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Manassas, VA 20109
ph.703 631 3430 fax.703 631 0234 www.dewberry.com

Date:7/7/2006	Job: River Oaks	BENCHMARK:
LOCATION: Structure 19 to 15		PARTY CHIEF: FORD
DESCRIPTION: **Sanitary Laterals**		PREPARED: JAA

Point	Offset	Station	Hub Elev	Prop Elev	Cut	Fill	Remarks
				SANITARY LATERALS			
							San Lat Unit #16850
1717	36' AHD	0+00	132.48	115.82	16.66		Crown @ San Main
1717	33' AHD	0+03	132.48	115.88	16.60		Begin Lateral Riser
1717	20' AHD	0+16	132.48	128.88	3.60		End Lateral Riser
1717	20' AHD	0+16	132.48	128.88	3.60		End San Lateral
							San Lat Unit #16847
1721	10' LEFT	0+00	115.40	115.94		0.54	Crown @ San Main
1722	10' LEFT	0+03	117.67	116.00	1.67		Begin Lateral Riser
1723	10' LEFT	0+19	119.34	132.00		12.66	End Lateral Riser
1724	10' LEFT	0+28	120.10	132.19		12.09	End San Lateral

NOTE: SURVEYOR DOES NOT TAKE THE RESPONSIBILITY FOR ANY ALLEGED ERROR OR DISCREPANCY FOUND IN THE FIELD OR ON THIS CUT SHEET UNLESS DEWBERRY AND DAVIS IS NOTIFIED IMMEDIATELY SO THAT THE MATTER CAN BE CHECKED AND RESOLVED. STAKES PLACED IN THE FIELD BY DEWBERRY AND DAVIS MUST BE UNDISTURBED AND IN PLACE SO THEY CAN BE FIELD CHECKED AND VERIFIED. CONTRACTORS MUST CHECK THREE OR MORE HUB ELEVATIONS PRIOR TO THE START OF CONSTRUCTION.

Figure 33.17 (*Continued*)

STORM SEWER STAKEOUT

A legitimate concern for any job site is how and where stormwater will drain. Even the most thoughtfully scrutinized plans can have a problem area, considering the unpredictability of Mother Nature, human error in construction, and the variable qualities of materials and equipment. At times, corrections are made in the field and in the cutsheets to ensure positive drainage and no ponding. Because it is such a critical component, storm sewer stakeout is frequently more exacting than other types of stakeout. Storm sewer structures, tops, grates, and throats must match the paving and the curb and gutter in the street, contours in graded lots, and existing swales in the outfall, in addition to carrying the required amounts of water.

Storm Sewer Structures in Street Rights-of-Way

Catch basin locations are determined by street geometry such as stationing, width, and slope. Typically, the storm sewer system is built before the curb and pavement of the street. The two critical dimensions used to determine the location of the structure are the centerline of street to face of curb and face of curb to centerline of structure. For the former, the party chief consults the plan view along the entire street length, watching for dimension contradictions or street transitions, and scales the dimensions shown on all the drawings. At street intersections the side street's plan view is checked in a similar fashion to determine the width of the street. Specifications for the structure type must be consulted to determine the distance from the face of the curb to the centerline of the structure.

Many contractors request stakes that relate the storm sewer structure to the face of curb. This is to ensure accurate placement of the structures for eventual matchup to the curb and gutter. Along tangent sections, offsets are set along the face of the curb with the offset distances, relating to the centerline of the structure, indicated on the stakes. In a curve, the offsets are placed on a line perpendicular to the radial line. The hubs may be placed to the left and right of the structure to allow the contractor to string line between, or they may be set to one side of the structure for a line the contractor can extend. Both of these methods are shown in Figure 33.18.

Checking the face-of-curb offset hubs is accomplished by calculating the hypotenuse distances from the centerline of the storm sewer structure or from the nearest centerline street station. When applicable, distances between face-of-curb hubs on parallel structures can be measured as an additional check.

The pipeline offsets are staked once the centerline of each structure and, if applicable, the face-of-curb hubs have been set. The offset distance is determined with the contractor and, again, by the depth of pipe shown in the plans and profiles (see previous discussion of dirt-pile and trench clearance in "Sanitary Sewer Stakeout" section). The issue of which side of the line to place the offsets on is usually determined by onsite conditions and practical considerations. Obvious choices include placing the offset on the side away from the street, on

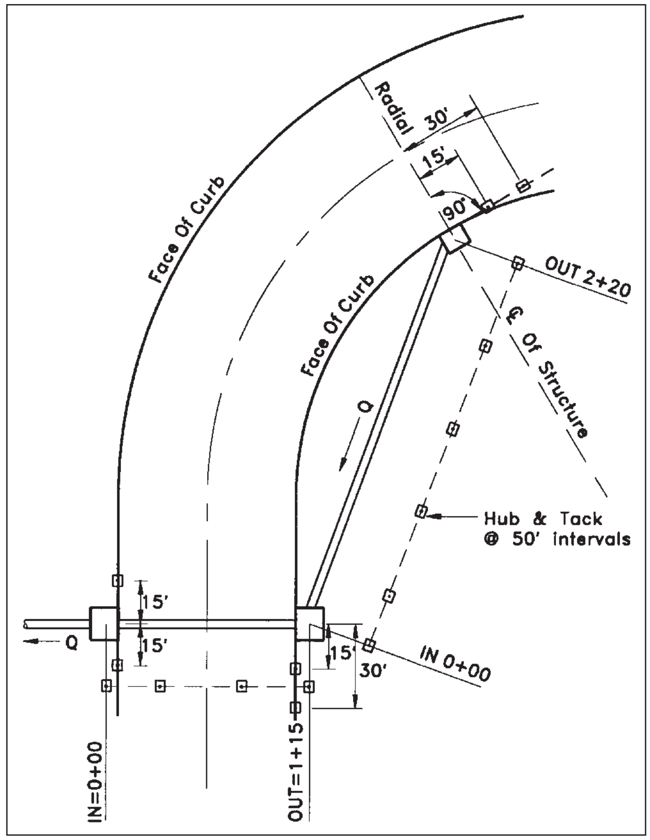

FIGURE 33.18 Face-of-curb offsets for storm sewer stakeout.

the side most protected from construction machinery, and/or on the "high side" of the construction area.

Similar to a sanitary sewer stakeout, the hub for the pipe that discharges into the downstream structure is designated as the OUT, with a station 0+00. The IN hub is the inlet side of the same pipe, at the next upstream structure, whose station is designated by the distance between the two structures. Offset hubs along the pipe length are set at 50-foot intervals, while any sanitary sewer lines or other pipe and utility crossings are offset as well. The stations for any crossings are referenced from the profiles. To have crossings staked in the field while also appearing on the cutsheet helps the contractor avoid contact with existing lines by maintaining the minimum amount of clearance. Elevations are run on the entire stakeout using a total station. (See Figure 33.19.)

Outfalls and Storm Sewer Structures in Nonpaved Areas

In many instances storm sewer easements are parallel or nearly parallel to property lines. The bearings of the property line and the easement will be compared to see whether they are parallel. After checking the record plat for the needed easement information, the party chief should check that the sewer line agrees with the plan and profile and note the distance between the centerline of the easement and the nearest property line. After ensuring that the storm sewer complies with easement restrictions, the stakeout then proceeds as outlined.

Storm sewer outfall structures (see Figure 33.20) must

Dewberry & Davis LLC

Project: Braemar Ph.2 Sec.21A
Job No: 87-018
01-00150

Battlefield Business Park
10525 Battleview Parkway Manassas, VA 20109

Tel #: (703) 631-3430
Fax #: (703) 631-0234
Page: 2

Storm Sewer Cutsheet

Grade To: Invert of Pipe or As Noted
Location: Str.30 - 31 - 32 - 33 - 34 - 35, 32 - 36 - 37

Prepared By: R. Root Date: 9/12/2001
Staked By: M. Cook Date: 9/11/2001
Checked By: Date:
File:

Description	Offset	Station	StakeElev	GradeElev	Cut/Fill	Comments
___SMSO36___						
STR32(IN) MH	15'RT	**00+00**	261.80	259.30	**C- 2.50 '**	204.01' - 15" RCP @1.57 %
	15'RT	**00+50**	263.82	260.08	**C- 3.74 '**	
	15'RT	**01+00**	264.48	260.87	**C- 3.61 '**	
	15'RT	**01+50**	265.96	261.65	**C- 4.31 '**	
STR36(OUT) DI-3B	15'RT	**02+04.01**	267.57	262.50	**C- 5.07 '**	
FC@STR36	15'LT	**13+73**	267.14	269.02	**F+ 1.88 '**	TOP OF CURB
FC@STR36	30'LT	**13+88**	267.44	269.02	**F+ 1.58 '**	TOP OF CURB
___SMSO37___						
STR36(IN) DI-3B	15'RT	**00+00**	267.10	262.60	**C- 4.50 '**	32.00' - 15" RCP @0.62 %
	15'RT	**00+16**	267.16	262.70	**C- 4.46 '**	
STR37(OUT) DI-3B	15'RT	**00+32**	267.04	262.80	**C- 4.24 '**	
FC@STR37	15'RT	**13+73**	267.08	269.02	**F+ 1.94 '**	TOP OF CURB
FC@STR37	30'RT	**13+88**	267.34	269.02	**F+ 1.68 '**	TOP OF CURB

USE A MINIMUM OF THREE (3) HUBS FOR LINE AND GRADE

FIGURE 33.19 Storm sewer cutsheet.

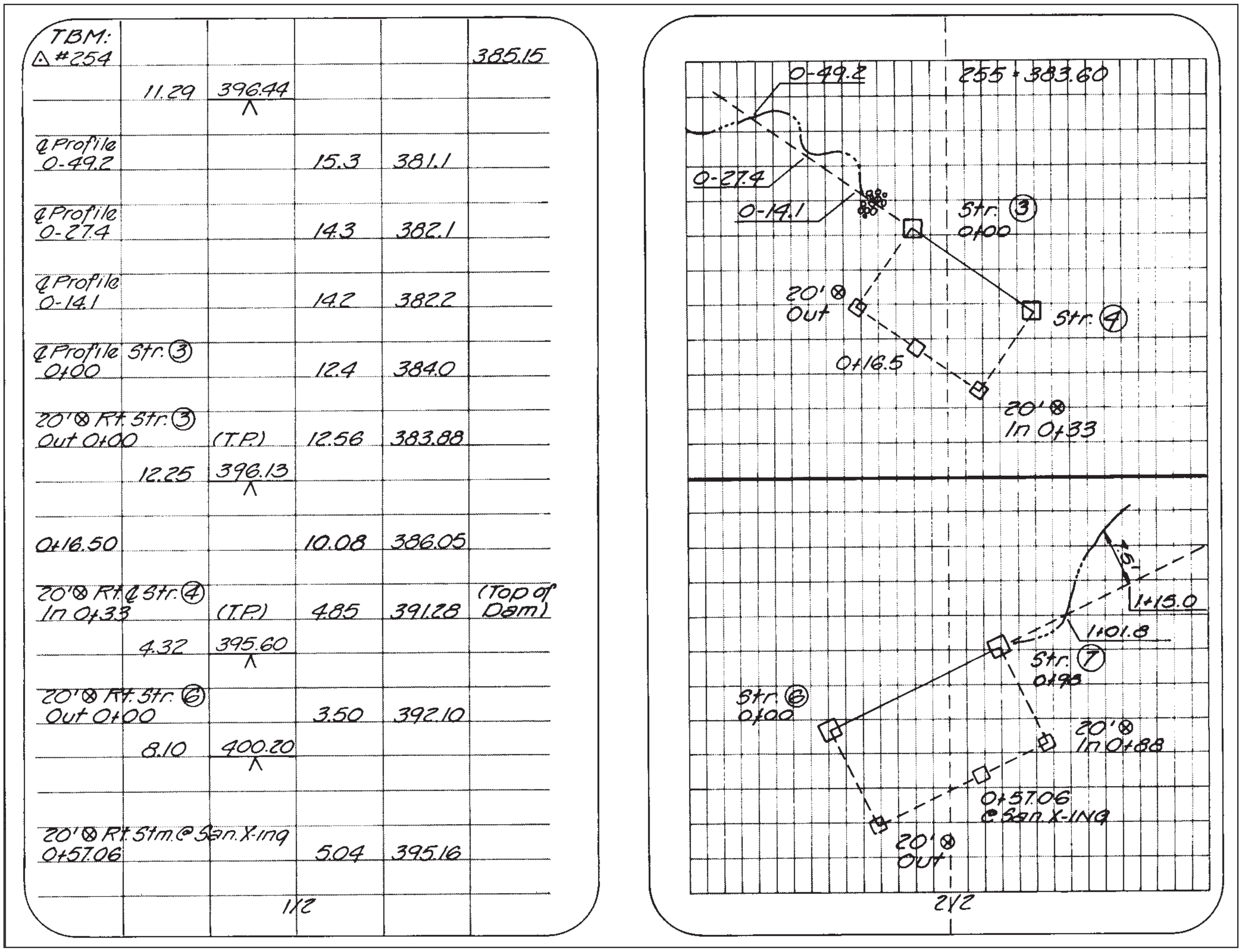

FIGURE 33.20 Storm sewer outfall notes and sketch.

match the existing discharge system horizontally and vertically, whether they are swales, ditches, streams, or ponds. Swales and ditches may exist naturally, but more often than not they are designed to transition the storm sewer system into the natural system. Some are made of concrete and are designed to channel stormwater directly into another structure in environmentally sensitive areas. In the field, the party chief may have to adjust the stakeout to create a better fit. In such cases, the new layout is located and the information is then sent to the engineer for confirmation.

When the storm sewer system discharges into a natural outfall, the survey crew takes the time to locate, vertically and horizontally, the outfall channel a minimum of 150 feet downstream from the point of discharge. The discharge point is designated as the OUT and, if it is assigned a station of 0+00, downstream shots are designated as −0+50, −1+00, −1+50, and so on. Any horizontal change of direction on the outfall should be noted and sketched, with a distance measured to the centerline of the bend and its elevation obtained. This information serves to verify the location of the storm sewer structure in relation to the limits of the easement and the natural drainage system. After all field stakeout work is complete, a cutsheet is prepared and copies delivered to the contractor and other appropriate agencies.

Stormwater Retention and Detention Ponds

Stormwater retention and detention ponds are staked along the proposed grading contours. Hubs are typically set to locate the toe of the proposed berm and also to mark the top of the proposed berm. Stakeout markers are set at horizontal bends and at regular intervals, to delineate the size and shape of the pond. A limited number of stakes should be used, as setting too many markers may conflict with the operation of large earthmoving equipment. The stakes set along the proposed contours are generally set at every two to three contour intervals for the same reason.

Preliminary preparation for this stakeout includes plotting traverse or other control points on the site plan. Coordinates of each pond point are computed. A total station and data collector may be used to stake the points, which usually consist of a hub and a 4-foot-tall guard stake. The hub is the horizontal and vertical point. The guard conveys the necessary information (written directly on the stake itself) such as the proposed contour or toe/top designation, the hub eleva-

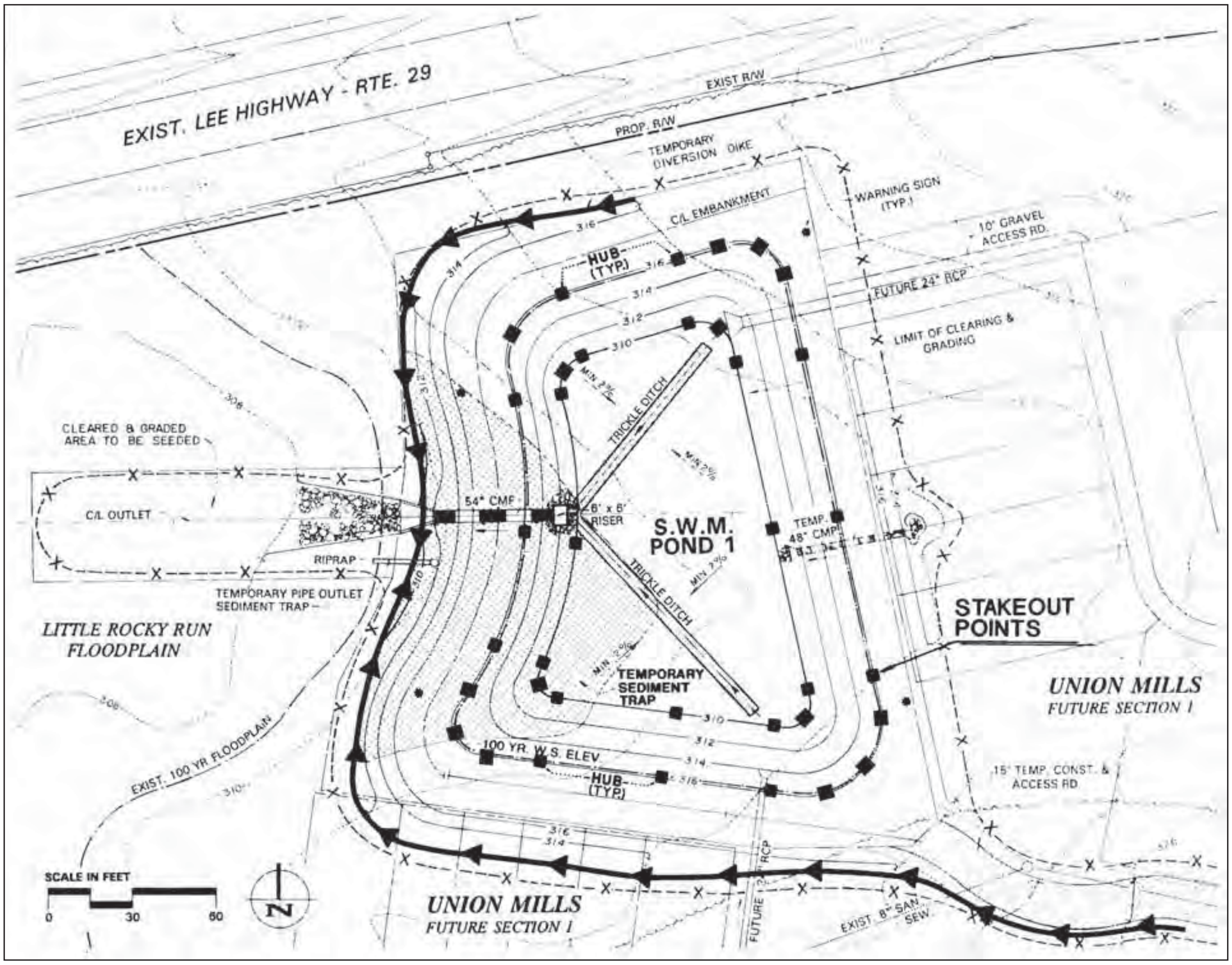

FIGURE 33.21 Pond contour and stakeout points.

tion, and the cut or fill information. A pond stakeout requires minimum accuracy; to the nearest foot horizontally and to the nearest tenth of a foot vertically, depending on the jurisdiction. (See Figure 33.21.)

WATERLINE STAKEOUT

Many waterline layouts are frequently designed to parallel (or closely follow) the centerline of the street and are profiled coincident with the street stationing. Although waterline pipe is manufactured in straight pieces, it can be installed on curve chord deflections. Other types of fittings are used for more abrupt change of directions. Such fittings include tees, crosses, bends of various angles, and wyes. The dimensions and stations of the waterline should be compared to the written information in the plans and profiles, verifying the location of all valves, fittings, and fire hydrants.

Double offset hubs are used to stake out tees and bends, while fire hydrants require multiple offset hubs (see "Fire Hydrants" section). The stakeout of the rest of the waterline is achieved by converting the centerline of the street into an offset line. This procedure is recommended if the distance between the centerline of the street and the centerline of the waterline is anywhere from 7 to 12 feet. The depth and width of the average waterline trench does not require a long offset.

The profile shows the horizontal and vertical path of the waterline and its relationship to the storm and sanitary lines. Crossings should be noted and staked, especially if there is minimum clearance either vertically or horizontally between the two utilities. If there are minimum horizontal clearances between the waterline and the sanitary lines, the waterline should be adjusted to maintain an adequate distance, especially if the waterline passes near the barrel vault of a sanitary structure.

In easement conditions, such as over terrain or through parking areas, the waterline will have its own stationing system shown in the plan and profile. This stationing must be adhered to as closely as possible, as this is the system approved by the local governing authorities. If there are inaccuracies, sometimes a station equality is placed on the stakes, noted by the plan and profile station first, followed by the equal sign, and the stakeout station. This allows for correction in the stationing, which matches the remainder of the stakeout to the plan stationing.

Fire Hydrants

Fire hydrants must be accurately placed horizontally and vertically. The stakeout is based on the relationship between the curb line (or edge of pavement/shoulder) and the main

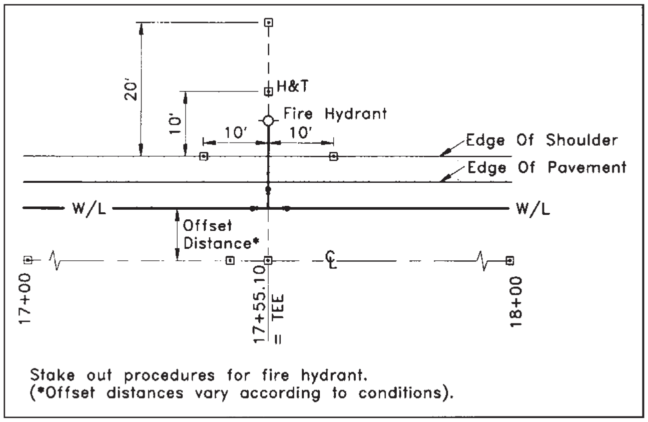

FIGURE 33.22 Stakeout procedures for fire hydrants.

waterline. The critical dimension, the distance from the centerline of the street to the face of the curb, is the reference point that controls the hydrant location. As shown in Figure 33.22, a hub marking the tee for the stub line leading to the fire hydrant is set along the offset line for the main waterline. Two offset hubs are set along the line and in the direction of the fire hydrant. These hubs are set beyond the fire hydrant, a minimum of 10 feet apart. Two hubs are then set, marking the face of the curb or the edge of the pavement. String lines stretched between the hubs marking the face of curb and from the hubs beyond the fire hydrant to the hub for the tee mark the intersection of the curb and the waterline stub to the fire hydrant. A guard stake is marked to indicate the elevation of the curb or the edge of the pavement and, from these references, the contractor can place the fire hydrant.

Hydrant installation is expensive and, due to the poured concrete surge block, very permanent. Setting the face of the curb and having the contractor install the hydrant to the code criteria involve a shared responsibility.

As an additional precaution, fire hydrant stakeouts are tied to other street or traverse control. The notes for hydrant locations are later checked and the stakeout location verified. When elevations are run, the rod is read once directly in a natural position, and then flipped and read inverted. The two readings should add up to the total height of the rod, thus verifying the accuracy of the initial reading. This procedure is used for three of the offsets; the fourth offset is employed as a turning point in the level circuit.

Valves and Other Waterline Fittings

Tees are 90-degree fittings, typically occurring at connections to existing lines, stub lines to fire hydrants, and intersections with other waterlines. They are staked with double offsets, one indicating the line direction back and the other indicating the line ahead. (See Figure 33.23.)

Horizontal bends in the waterline are also staked with double offsets, each one set 90 degrees from the direction of the line it is representing. Both bend offsets carry the same station, as they address the same point. To distinguish them,

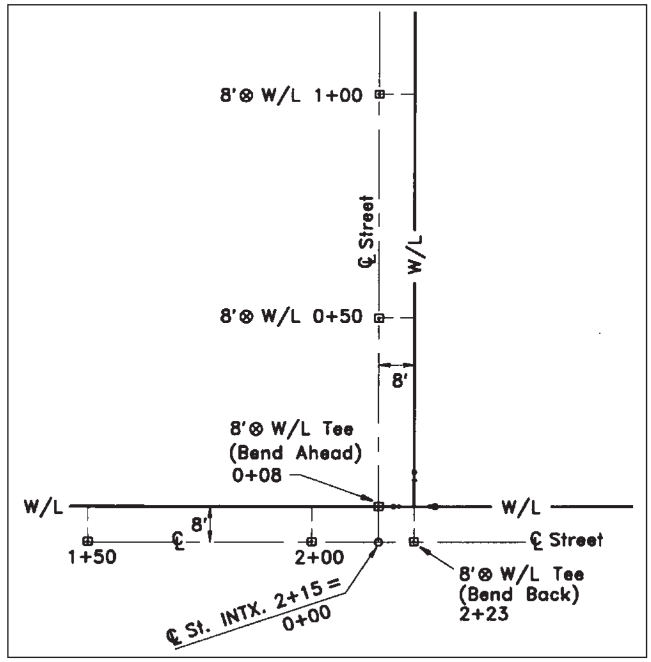

FIGURE 33.23 Waterline tee offsets.

one is called the *bend back* and the other is the *bend ahead*, based on the stationing system and its point of beginning.

Blow-off valves are located at the end of a waterline. In some cases, they deviate from the street centerline. The plan view location is then compared to the profile. Intervals between offset hubs between tees, bends, and valves are often 50 feet, but 25-foot intervals are sometimes employed in horizontal and vertical curves.

Service Lines

A separate stakeout is made for water crocks, which mark the limits of public service and from which the private line extends to serve the lot. Water crocks contain the meters and cutoff valves for each service line. The crock location is marked either with paint on the curb or with hubs and guards. There is usually a code distance between the property line and the crock. Either the property line is marked at the point where the crock is to be installed or the property line is referenced by offsets in order to preserve the stakeout. The water crock can also be staked inline with the stub, just beyond the property line. One offset with an elevation given for each crock is generally all that is necessary to build the crock and its lateral from the main.

Waterline laterals that service high-rise office and apartment buildings are staked with multiple offsets, indicating the tee location, intermediary station(s), bends, and the connection to the building. The site of the existing building connection may differ from the plan, as architectural plans are not always finalized before the site plans are designed. A consultation with the contractor or plumber is recommended before designing building connections. At times, dimensions pinpointing the plumbing inside the building are measured and re-created outside to locate the connecting point. The stakeout then proceeds in the described fashion. (See Figure 33.24.)

Dewberry 10003 Derekwood Lane Lanham, Maryland 20706-4804 ph.301 731 5551 fax.301 731 0188 www.dewberry.com					CONTRACT #______ SHEET# __1__ OF __1__ REVISION DATE ______		CS#021
Date: 1/9/07		Job: RIDGES 2&3			BENCHMARK:		
LOCATION: *WOODREED DRIVE*					PARTY CHIEF: DV		
DESCRIPTION: **WATERLINE STAKEOUT**					PREPARED: DSD		
Point	Offset	Station	Hub Elev	Prop Elev	Cut	Fill	Remarks
WATER LINE STAKEOUT WOODREED DRIVE							
1516	10' RT	0+00	TEST PIT	215.30	TEST PIT		OS10 WL (TEST PIT)
1517	10' RT	0+15.85	220.91	215.11	5.80		OS10 WL
1518	10' RT	0+50	220.79	214.70	6.09		OS10 WL
1519	10' RT	1+00	219.31	213.50	5.81		OS10 WL
1520	10' RT	1+50	216.07	211.60	4.47		OS10 WL
1521	10' RT	2+00	212.92	208.85	4.07		OS10 WL
1522	10' RT	2+50	208.81	206.10	2.71		OS10 WL
1523	10' RT	3+00	204.76	202.30	2.46		OS10 WL
1524	10' RT	3+50	200.37	198.10	2.27		OS10 WL
1525	10' RT	4+00	195.85	193.20	2.65		OS10 WL
1527	10' RT	4+24.51	193.25	190.75	2.50		OS10 WL
1528	10' RT	4+50	190.81	188.20	2.61		OS10 WL
1529	10' RT	4+95	186.39	182.70	3.69		OS10 WL
1530	10' RT	5+25	182.99	180.50	2.49		OS10 WL
1531	10' RT	5+64	178.87	176.48	2.39		OS10 WL
1546	0	5+64	179.03	182.07		3.04	CL FH (EDGE PAVING EL.)
1545	10'	5+64	178.63	182.07		3.44	OS10 FH (EDGE PAVING EL.)
1532	10'RT	6+07/0+00	174.45	171.90	2.55		OS10 WL
1534	10'RT	6+17.99	173.26	170.73	2.53		OS10 WL@ WV
1535	10'RT	6+50	169.70	168.50	1.20		OS10 WL
1536	10'RT	7+00	164.27	163.50	0.77		OS10 WL
1537	10'RT	7+50	159.22	158.50	0.72		OS10 WL
1538	10'RT	7+95.32	154.95	153.97	0.98		OS10 WL
1539	10'RT	8+00	154.58	153.50	1.08		OS10 WL
1540	10'RT	8+50	150.80	148.50	2.30		OS10 WL
1541	10'RT	9+00	147.37	143.50	3.87		OS10 WL
1542	10'RT	9+40	141.68	139.50	2.18		OS10 WL
WATER HOUSE CONNECTIONS							
1543	10	LOT 9	169.46	165.00	4.46		FINAL GRADE
1544	10	LOT 4	165.83	172.00		6.17	FINAL GRADE
NOTE: SURVEYOR DOES NOT TAKE THE RESPONSIBILITY FOR ANY ALLEGED ERROR OR DISCREPANCY FOUND IN THE FIELD OR ON THIS CUT SHEET UNLESS DEWBERRY IS NOTIFIED IMMEDIATELY SO THAT THE MATTER CAN BE CHECKED AND RESOLVED. STAKES PLACED IN THE FIELD BY DEWBERRY AND DAVIS MUST BE UNDISTURBED AND IN PLACE SO THEY CAN BE FIELD CHECKED AND VERIFIED. CONTRACTORS MUST CHECK THREE OR MORE HUB ELEVATIONS PRIOR TO THE START OF CONSTRUCTION.							

FIGURE 33.24 Waterline cutsheet.

CURB AND GUTTER STAKEOUT

Curb and gutter is staked from accurate control and referenced to the street centerline. Using a copy of the record plat, construction drawings, and the stakeout hard copy, the street's main control points are set and ties are made to existing traverse control or other street references as a check for accuracy. Before staking the site plan, street profiles and typical street sections are thoroughly checked for street width(s), transitions, vertical curves, radius dimensions, and parking space dimensions (where applicable). Each item mentioned is an integral part of the curb and gutter stakeout procedure. The following method provides sufficient guards to accuracy.

The main points, including point of curves (PCs) and point of tangents (PTs), are usually reflected in the layout of the curb when the curb is parallel or concentric to the centerline. Other points identifying stations where street width transitions begin and end, intersecting streets, street entrances to commercial property, and stations corresponding to curb returns are set along the centerline as the stakeout progresses. The major points for the curb are transferred laterally from the centerline (90 degrees in tangent, radially in curves) at the prescribed distance to the face of the curb plus the offset distance. Seven- and ten-foot offsets are commonly used, as this is often the distance to the property line and convenient for use with a slip form paver (curb and gutter pouring machine).

For a curb return (the point of curve or point of tangent at a street intersection), the 90-degree (tangent) or radial (curve) line from centerline also sets the radius of the return. Although 50-foot intervals are adequate along tangent sections, 25-foot intervals are used through horizontal and vertical curves. Points along a horizontal curve on the curb-offset line are set the same way as staking out a horizontal curve.

To prove out a point between main stations, the distances from each end must be checked. On a curb and gutter stakeout involving the placement of driveway aprons, each distance between driveways should be measured and the sum of the increments compared to the total distance, to eliminate any error. When staking a curve, the total deflection angle and distance are checked first, then the intermediate stations are set. The final check-in distance proves the accuracy of the intermediate points set.

Other features should be checked as the curb and gutter stakeout progresses. Distances (and occasionally angles) are measured to storm structures, sanitary manholes near the curb line, fire hydrants, and the match point where existing curb and gutter meet the proposed curb and gutter. The plans are frequently consulted to see that the design locations of such features have been constructed or located in the field properly. If there are any overt discrepancies, those features are located. If time allows, the notes are taken to the office for review and to perform calculations to verify field procedures and previous computations. This must be done immediately before the contractor begins construction.

Curb Offsets through Street Transitions

Street transitions occur when the street changes width between intersections due to the addition of turn lanes. The transition occasionally occurs on one side of the street only or on one side of the intersection only. Transitions also occur with the addition of a lane to increase traffic capacity.

A smooth transition design can simply be two reverse curves. The beginning, midpoint, and end of transition points are set at their stations along the street centerline. Then each is offset radially behind the face of the curb at the transition widths noted in the plans. If the curves are equal in length, the distance to the midpoint, which is the point of reverse curve, will be half the difference between the two ends. (See Figure 33.25.)

Cutsheets for Curb and Gutter

Horizontally, curb offsets are always staked in relation to the face of the curb. Vertically, the top of the curb is frequently used as the reference point. Preparation of a cutsheet for streets with constant geometry is straightforward. The proposed street grades can be determined from the profile and the typical section. This grade is compared to the existing elevation, obtained from the stakeout notes, and the corresponding cut and fill depths are entered onto the cutsheet.

Where the proposed curb design connects to an existing curb, a minimum of three top-of-curb elevations along the existing curb at 25-foot intervals are obtained as the stakeout is run. This provides the cutsheet preparer with the information needed to check how well the newly constructed curb matches the existing curb. If the proposed grades do not match the existing grades, the cut sheet preparer should consult with the engineer. Otherwise, the cut sheet preparer, using good judgment, may make slight adjustments to the elevations to provide a smooth vertical connection between the existing and the proposed curb and gutter.

A frequent problem when preparing cutsheets of curb and gutter for parking areas is a misinterpretation of the elevations listed on the site plan. Whereas the proposed top-of-curb elevations can be found in the street plans and profiles, curb elevations may not be as readily available on plans of areas where uniform geometry does not exist, such as parking areas or combination travelways and parking frequently used in town house projects. Since parking areas are warped to facilitate drainage and to accommodate the site conditions, spot elevations are used in conjunction with grading contours in the design. Drainage problems or uneven curb and gutter sections may result if spot elevations are too sparse or are not properly interpreted by the preparer of the cutsheet.

In such cases, the person preparing the cutsheet must check the viability of the proposed top-of-curb elevations throughout the stakeout area. A careful inspection is made of

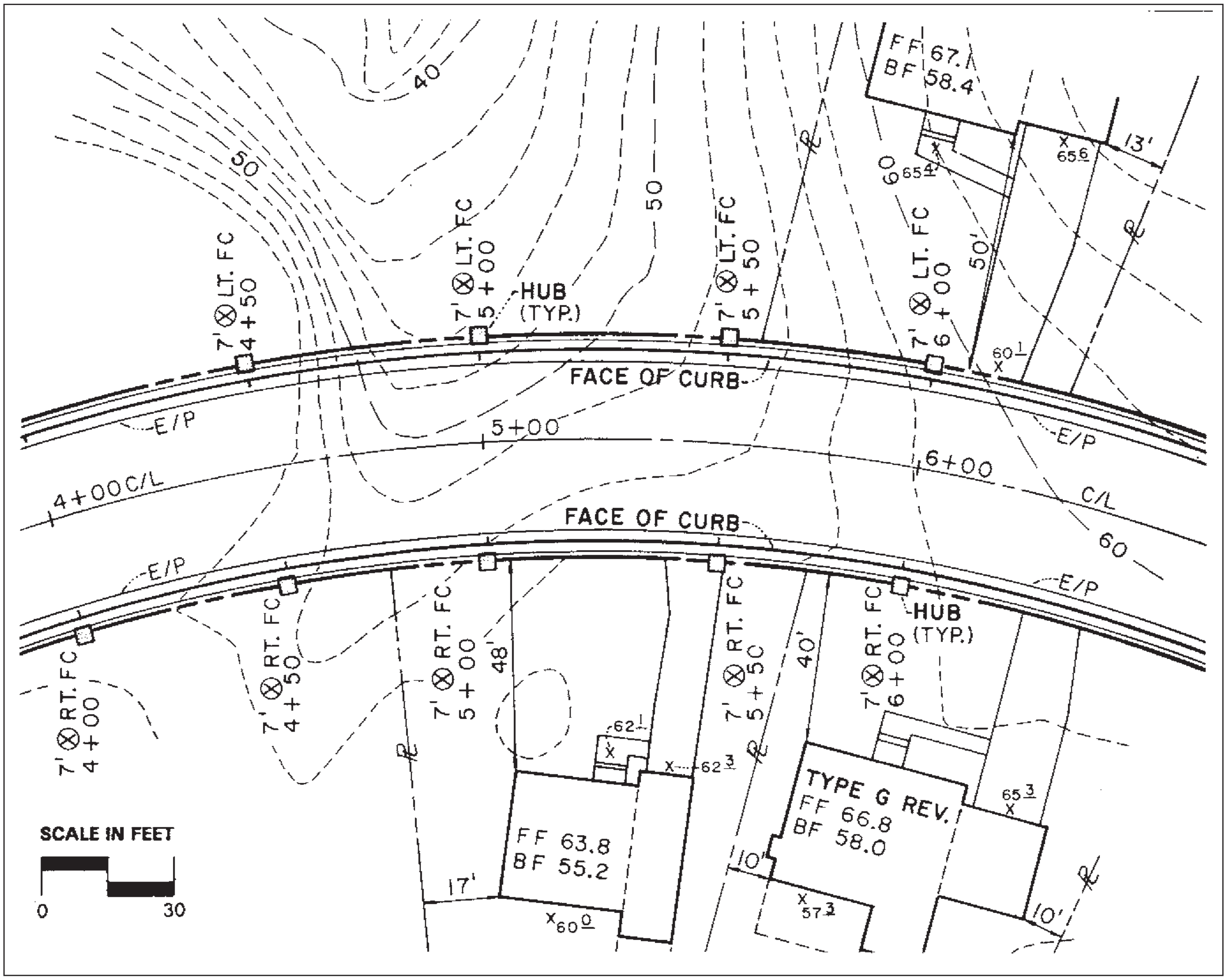

FIGURE 33.25 Curb stakeout offsets in a curve.

the proposed topography to ensure that the new curb and gutter will actually channel stormwater to catch basins and drains. Additionally, the cutsheet preparer must provide for smooth vertical transitions along the curb line.

To illustrate how misinterpretations of elevations arise, consider the following example. In addition to a combination curb and gutter section with a 0.5-foot-high curb and a 2-foot-wide gutter pitched toward the curb, some municipalities allow (only in specially designated areas) a curb and gutter combination with the pitch of the gutter away from the face of curb. The gutter pitched toward the curb concentrates flows to increase the hydraulic efficiency of catch basins. In parking areas, the use of the reverse-pitch curb and gutter combination reduces the number of storm sewer inlets and allows for more flexibility in the design. The difference in elevation between the edge of the pavement at the lip of the gutter and the top of the curb is different in each case. In preparing the cutsheet, the location of each different curb must be recognized when obtaining the top-of-curb elevation.

Curb and Gutter Stakeout in Town House and Parking Areas

Town house and parking lot curb and gutter stakeouts are generally performed as previously described. However, there are a few additional items to consider. Chief among them are travel lane widths, parking bays, islands and medians, and depressed curbs for ramps.

In some areas, municipal code may dictate a minimum width for travel lanes, particularly to ensure accessibility to fire and rescue vehicles. It is wise to know the minimum standards and check the site plan for discrepancies before proceeding with the stakeout.

A parking bay is designed to contain a certain number of vehicles, usually noted on the site plan along with the width of each space. The number of parking spaces multiplied by

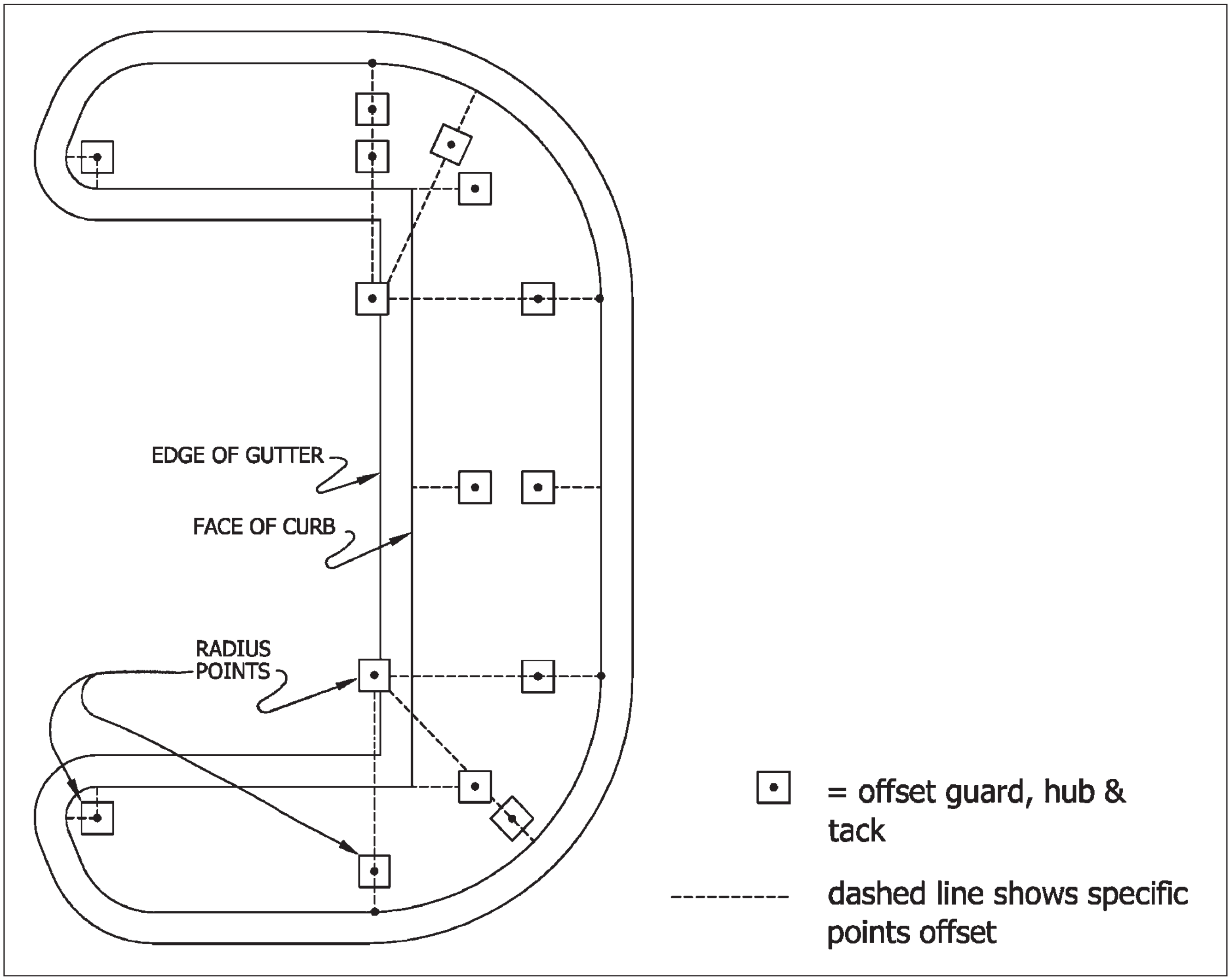

FIGURE 33.26 Parking lot curb island stakeout example.

the width of each space should equal the distance between the two corners of the bay. This should be compared to the stationing system to ensure the distance is accurate. If there are any handicap parking spaces, the additional width should be added to the total distance as well.

Islands are often used to channel traffic, to create additional parking, or to accommodate central features such as tot lots, community mailboxes, light poles, fire hydrants, and entrance gates. Generally, islands that channel traffic are called ***medians,*** and they may consist of solid concrete or curb and gutter on each side with a planted strip in the center. Some may incorporate transitions to accommodate turning lanes. Depending on the size and shape of the median, the contractor may request a single row of offsets down the middle or two rows of offsets, each dedicated to one side of the island. If the latter is requested, it is preferable to offset each side away from the center to avoid confusion of crossing offsets. Medians usually terminate in small curves, so the radius points should be clearly marked and graded for inclusion on the cutsheet. (See Figure 33.26.)

If an island incorporates utilities such as fire hydrants, storm sewer structures, sanitary manholes, or light poles, checks should be made in the field to ensure proper matchup and/or containment of these features, both horizontally and vertically.

Finally, the location of depressed curb for handicap ramps, public trails, or loading zones may be a required part of the stakeout. A careful study of the site plan reveals that the public area locations and record plat will aid in the siting of trails within easements.

BUILDING STAKEOUTS

The types of buildings typical in land development projects include single-family detached residential units, single-family attached units (town houses), and low- and midrise retail and commercial buildings. Two important considerations in establishing the building location for the stakeout survey are adherence to zoning setback restrictions and allowable accuracy for construction. Although the building is shown conforming to setback restrictions on the plans (otherwise the

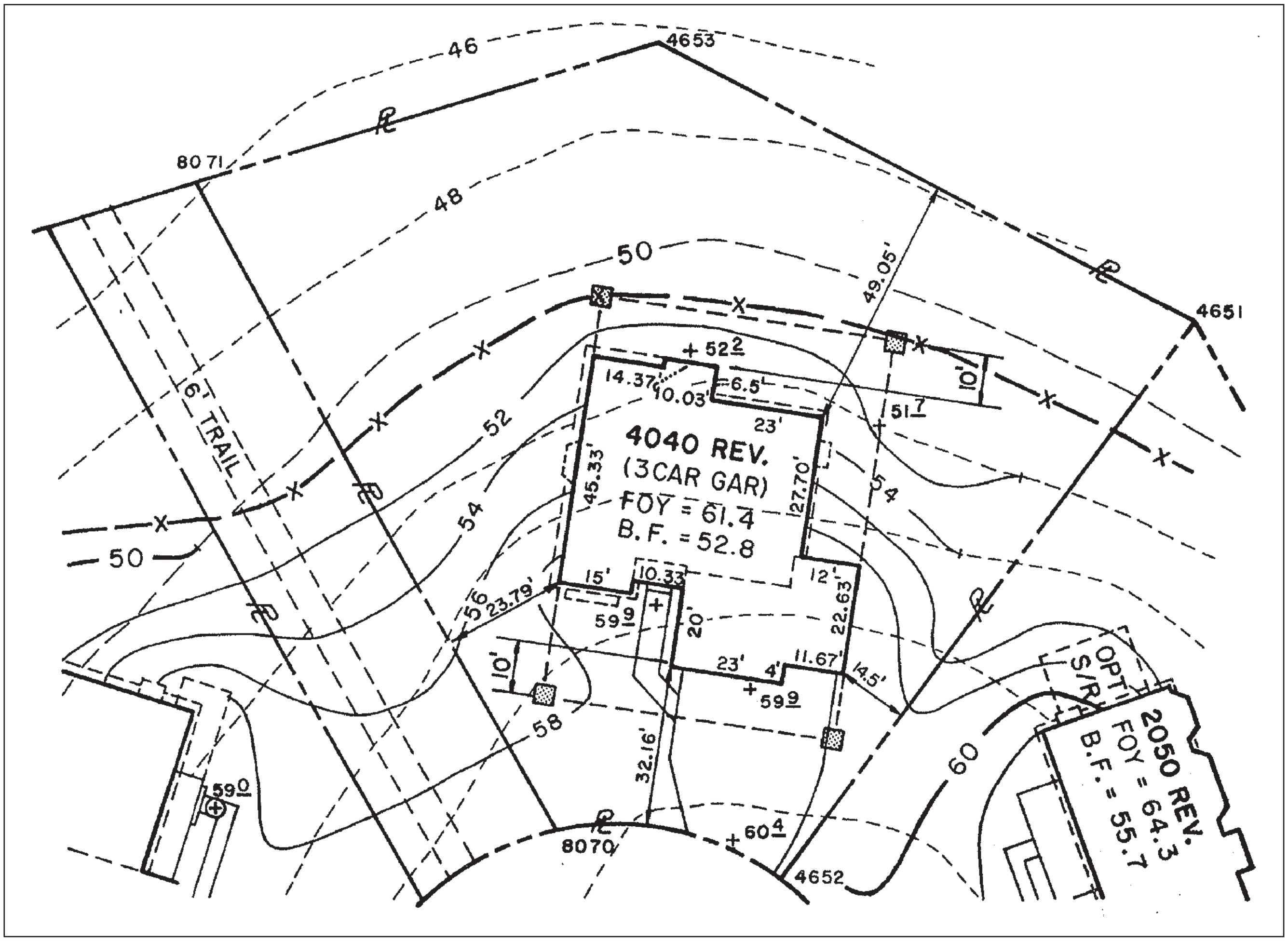

Figure 33.27 Building grading stakeout.

plans would not have been approved), the stakeout computations and the subsequent field procedures must ensure the field location with the plan location. Additionally, the dimensions of the building and the corner angles must be set to within the tolerable limits required for construction purposes. Building stakeout can be as straightforward as setting offset stakes for four corners or as complex as setting column line locations for a high-rise structure.

Several construction phases of a building require separate stakeouts: grading, building layout, footing, and brick point stakeouts. In most cases, all of these are used for residential construction. However, commercial buildings and other types with atypical foundations or special design characteristics may require unique stakeout methods different from those mentioned.

Grading Stakeout for Buildings

Preliminary preparation of a site involves the removal of topsoil and the manipulation of the earth to bring it to subgrade level. To accomplish this, the contractor requires a grading stakeout. The most expedient method extends the outermost lines of the building to create a simple rectangle whose corners are staked with offsets. Usually, a 10-foot offset is sufficient to enable earthmoving equipment to move about freely and yet retain the stakes for horizontal and vertical referral. Since this stakeout is intended merely to guide rough grading, the hubs are not tacked, but they are guarded with tall stakes for easy visibility (see Figure 33.27).

The offset markers are computed using computer-aided design (CAD) and overlaid on the grading plan in preparation for the field crew. Once the grading stakes are set and checked, the final location is stored in the data collector for office personnel to verify the stakeout and perform cutsheet calculations. The elevations are marked on the back of each guard. The field notes are checked by office personnel, and a cutsheet based on finished basement floor grades is issued for the contractor's use.

Construction Stakeout for Buildings

Once the rough grading operation is complete, the building is staked for construction. First the location of the building and then the corresponding offset hubs are established based on the grading plan or the site plan. To ensure compliance of zoning setback requirements, computing the building location should be based on its relationship to the property lines.

Coordinates are set for each corner of the building. Cor-

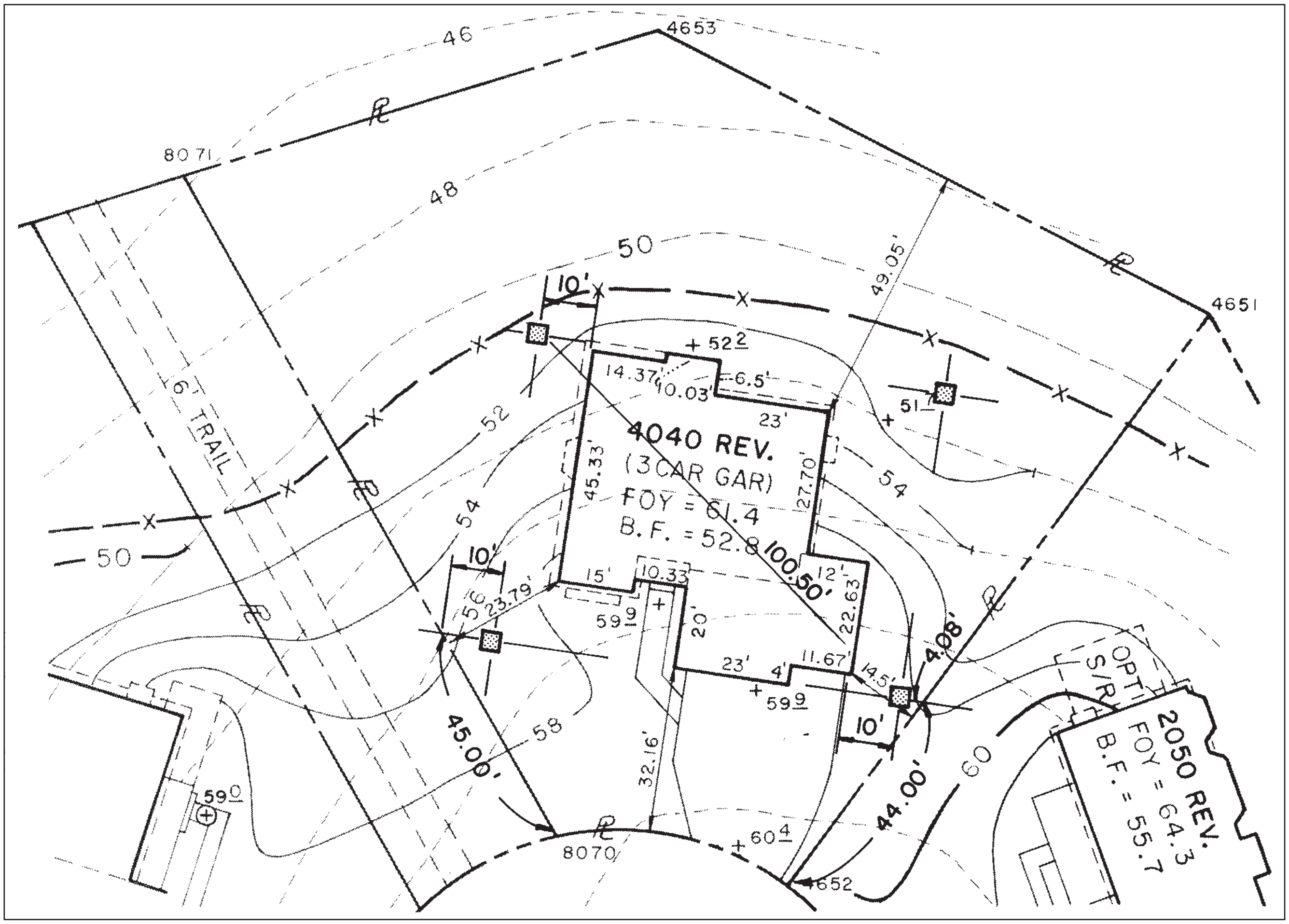

FIGURE 33.28 House stakeout showing 10-foot side offsets.

responding point numbers are assigned and recorded on the building stakeout sheet. Once all the building coordinates are set, the actual setbacks and side-yard distances can be computed. Check to see that all setback distances to property lines comply with local code and restrictions. Due to expensive land and rising development costs, planners strive to maximize the number of houses on a site, using the minimum restriction lines. For this reason there is little room for movement, or error, in the stakeout of a building. As another precaution, a computer plotting should be made and overlaid on the development plan to check compatibility.

Most building stakeouts use 10-foot offsets; this distance is sufficient to accommodate the overdig of the basement or the foundation and is short enough for the contractor to use accurately. The proposed 10-foot offsets are drawn onto the stakeout sheet; the placement is usually from side to side, but front-to-back offsets can be used as well. The front side-to-side offsets will be on the face of building line 10 feet from the edge of the squared building. The offsets are assigned point numbers and coordinates.

The building stakeout sheet (see Figure 33.28) will have coordinate point numbers written next to each lot corner, at intersection points on lot lines, on offset points, and at the building corners. Stakeout tied from control points to the offset hubs of the corners of the building may also be shown. A list of the point numbers and their coordinates is attached to the stakeout sheet to facilitate any necessary field computations. In addition, the side-yard distances and the minimum distances as prescribed by zoning regulations are given. Curve information is also supplied where applicable. A copy of the building stakeout sheet is placed on file and a copy is used by the survey crew.

After the building offset points are set, it is good practice to turn angles and measure distances to other control points that are independent of the stakeout procedure to verify the stakeout. For practical and legal purposes, many surveying companies require that a location be made of the building stakeout. Some may furnish a preprinted form along with the stakeout sheet; one side is a photocopy of the building stakeout sheet and the other is a standardized form with prompts and spaces for answers necessary for the record.

Elevations are run using at least two benchmarks, and a front offset hub is established as a temporary benchmark by using it as a turning point in the level circuit. The lowest floor elevation furnished on the development plan, whether it is low basement, Basement, or first floor, is used to calculate the earthwork cut or fill to finish floor level. In undisturbed areas, it is wise to record elevations at the building corners to check the topography. On-site, the hub elevation is written on the stake along with the cut or fill amount. Off-site, the field notes and the elevations are checked and a formal cutsheet is issued.

Footing Stakeout. After the area is excavated, contractors frequently request a footing or foundation stakeout. The building stakeout offset hubs are recovered or replaced, checked, and then used to lay out the actual building corners. The front (or rear) building offset line may be used as a baseline to transfer the corners to the foundation excavation. Another method is a radial stakeout, occupying one offset and using coordinates of each building corner to determine bearings and distances from the setup point. The latter method can be employed successfully if all distances between footing points are checked thoroughly. Diagonal measurements between footing corners are truthful checks of squareness.

The vertical portion of the footing stakeout consists of setting a grade marker, established as a temporary benchmark by using it as a turning point when the level circuit is run. This point is used as a vertical reference to finish grade.

Brick Points. After the footing is poured and set, the building is ready for a brick point stakeout. This consists of setting concrete nails in the footing at each corner or jog of the building. These are used by masons (block walls) or a forming crew (poured walls) to align the building walls. The stakeout should be very accurate to provide a square foundation for subsequent work.

Temporary surveyor's tacks can be set as points on a baseline used by turning 90-degree angles to rear jogs in the building. An alternative is to set the points radially from one point, but this approach dictates the need for extreme care in the setting of each point; otherwise, losses in accuracy may occur, particularly in the squaring of the building. A third method uses a compromise of these two methods. The front baseline is set and a combination of 90-degree angles and trigonometrically calculated angles and distances is figured from each main point. The distance between each nail is carefully checked. Generally, the method that provides the most accuracy is the one that relies the least on correction of slope distances. Since the building stakeout offsets are away from the basement hole and therefore much higher in elevation, large vertical angles are the correcting force for slope-taped or total station distances. A small variation in the vertical angle read, or the correction figured, will result in error. When setting brick points that will be placed in a deep foundation hole, it is often best to diligently set the first point as described, and then set the instrument in the foundation hole for subsequent points. Also, each time the instrument is moved to another nail, a backsight and a check foresight should be made to establish the accuracy of the nail occupied, before setting any other points.

Vertically, masonry brick points often require grade pegs set to finish floor grade. This involves setting a stake so that the top is equal in elevation to the finish floor grade (or an even foot higher or lower, as convenient). Another method uses a stake with a nail driven into its side at grade. Using poured-wall brick points often circumvents this formality, because the foundation is already in place and functions as the critical vertical surface in relation to the finish floor grades. Some survey companies check the elevation of the footer as a precaution for a poured-wall brick point stakeout. An on-site consultation with the client can determine the necessity of a level run.

Single-Family Attached Units (Town Houses). Stakeout for town houses proceeds through the same stages as for detached dwellings. The main difference is the need for more offsets to delineate each unit. The overall building, which typically consists of three to nine individual units, is squared as a whole, and its relationships to side, front, and rear property lines are determined. The four front corners of the town house block are set and checked first and then the front and rear property lines may be used as offset lines.

In Figure 33.29, the distance from the side lot line to the building on lot 14 has been computed at 9.25 feet. This distance is measured along the front property line, where a hub and tack is set, and its stake is marked 16 feet, offset to the left front building corner. Figure 33.29 shows the dimensions along the front and rear of each unit, but for the stakeout the centerline of the wall dimensions is used. Since 23.08 feet is the distance to the outside corner along the front face, a distance of 22.75 from the left front corner to the centerline of the wall results if the wall thickness is 8 inches (i.e., $23.08 - 0.33 = 22.75$). Therefore, a distance of 22.75 feet is measured along the property line, and another hub and tack is set. This stake is marked 16 feet offset to centerline of wall lot 14 and 17 feet offset to the centerline of wall lot 15, using the appropriate symbols and abbreviations. Continuing down the line in this fashion, the stakeout's accuracy is checked by measuring from the last offset—the right front corner of the building—to the lot corner. As shown in the example, the check-in is 9.67 feet.

This accomplished, the two building corner offsets are occupied, a 90-degree angle is turned, and the rear building corner offsets are staked on the rear property line. Moving the instrument to the rear line, the 90-degree angle and the distance are checked before staking the remainder of the rear line offsets. As mentioned in the previous section, the surveying company may require that a location be made of the stakeout. The cutsheet will provide cuts (or fills) to the finish basement grades of each unit.

The footer stakeout is accomplished just as described in the single-family dwelling section. Brick points may be set at the actual corners using the dimensions shown along the front and rear lines of each unit. Some contractors may request brick points on the centerline of walls. If so, the simplest method is to occupy each front offset, backsight the front offset line, turn 90 degrees, and check to the corresponding rear offset. Then, using lot 14/15 on Figure 33.29 as an example, the distances measured from the front offset would be 16, 17, 53, and 57 feet.

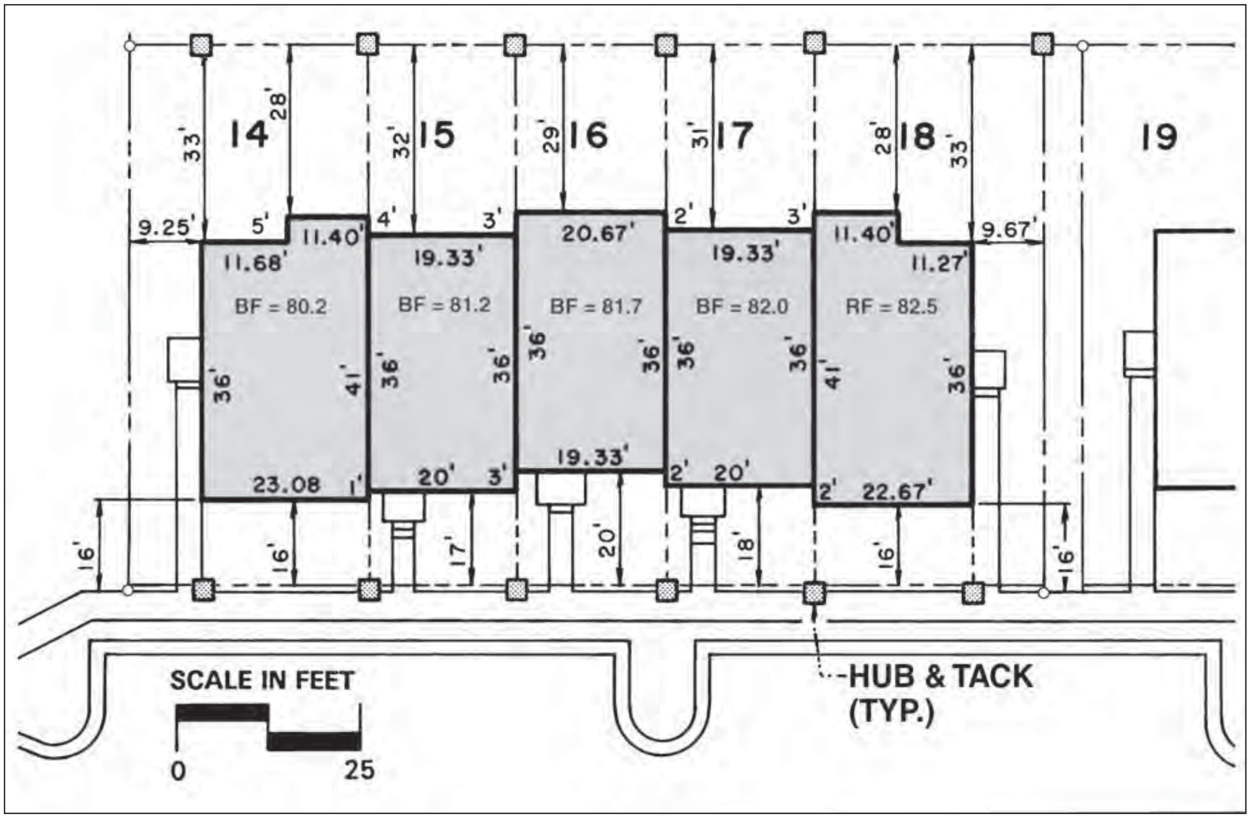

FIGURE 33.29 Typical town house layout for construction.

Commercial/Retail Buildings. A large building may be controlled by column lines, baselines, or specified control points, depending on the structure's configuration. The key to successful layout is to maintain high standards of accuracy and to reference the building control network off-site.

A great deal of preparation precedes the layout: traverse control must be set and computed, vertical control established and verified, and architectural plans scrutinized and checked. Ties from the traverse control to the building's control points are computed next, and a stakeout plan is drafted for the survey crew. The instrument has been checked and recalibrated, if necessary, and the optical plummets on all tribrachs have been checked and adjusted.

On-site, extra precautions are taken to maintain high standards of accuracy. The instrument should have good, solid setups. Angles should be double-centered.

Each time the instrument is fine-leveled, the backsight and the ensuing foresight should be achieved as quickly and efficiently as possible. The longer an instrument occupies a point, the more its chance of settling, thus producing error. Double-centering to eliminate error in the plates and turning angles while the setup is still fresh helps to prevent angular drift. The backsight is taken and the foresight angle is turned. The head chainman sets a sight stake on that line and pencil-marks the top. The instrument operator then reloads the backsight angle 180 degrees different from the first sighting, and turns to the foresight line, now 180 degrees different. This may be done several times. The head chainman marks the new line on the top of the stake. There will probably be a discrepancy between the first and second (or subsequent) marks. This discrepancy is divided in half, and a tack is driven at the mean mark for a visible sight on the foresight line. The instrument operator monitors this sight as points are set.

Once the sightlines are established, the distances are measured for the building points to be set. Distances should be checked using a prism mounted on a tribrach and tripod. All the control lines should be extended and referenced off-site, as any subsequent restake must match the initial stakeout. Appropriate checks for squareness should be performed, that is, turning 90-degree angles and measuring diagonal distances. Finally, all stakeout points and references should be located from traverse control, so that they can be checked in the office and filed for future reference.

Elevations are determined using the trigonometric means described here. On-site, the hub elevations are written on the stakes. In the office, the field notes and the elevations are verified and a formal cutsheet is issued.

SUMMARY

Construction stakeout requires substantial preparation before sending the survey crew to the field. Successful computing requires familiarity with construction techniques as well as good surveying skills. Inevitably there will be times when the survey crew will have to adjust the stakeout procedure in the field due to unforeseen job-site conditions. Therefore, the field crew must take all of the plans, plats, and hard copies as well as geometric coordinates with them in order to perform calculations necessary to complete the task. Contractors hate to have their workers and equipment stand idle. Delays due to poorly prepared survey crews cost them time and money. The procedures for the various stakeout methods described here are intended as a suggestion of the ways to perform construction stakeouts. Many localities have regulations that dictate construction methods and preferences for performing construction stakeout based on local conditions and biases. In addition, many surveyors have adopted other ways to perform stakeout work based on the type of instruments (both field and office) at hand, local contractors' preferences, and field conditions, and because they have found what works best for them given all the tangible and intangible factors. Before employing any of the foregoing methods, it is best to consult local ordinances and public agencies to avoid conflicts and to ensure compliance with the prevailing regulations.

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CHAPTER 34

CERTIFICATES OF OCCUPANCY AND POSTCONSTRUCTION SERVICES

Lawrence A. McDermott

Updated/Revised: George A. Wigfield, PLS

INTRODUCTION

In order to ensure that proper construction practices are followed, as well as minimize responsibility for faulty construction, most municipalities have a series of required postconstruction permits and certifications. Typically included in the series are occupancy permits and certain locally regulated as-built surveys or other construction verification documents. Municipalities require these postconstruction documents to confirm that proposed buildings, including site infrastructure components, are structurally sound and built in conformance with approved plans and local, state, and federal applicable codes.

Most municipalities require applications for occupancy permits (sometimes referred to as *use permits*) prior to full-time occupancy of the premises. This permit stage allows the municipality to perform a final inspection of the structure to verify that it was built as required. Beyond the final building inspection and verification required for an occupancy permit, many jurisdictions require as-built surveys and/or a record plan to verify site components, check the adequacy of installed public infrastructure facilities, and confirm the appropriate location of proposed easements in relation to installed facilities. These documents represent the final stage in the construction process, after which the municipality is often willing to release preconstruction bonds and accept streets into the public road system.

As indicated in the project cycle diagram (Figure 28.1) in Chapter 28, the operations and maintenance phase of a project is a critical but somewhat overlooked component of the land development process. The advent of smart drawings combined with the increasing capabilities of geographic information system (GIS) databases and new approaches to low-impact or sustainable development have resulted in a demand and need for the land development consultant (typically the engineer or surveyor) to provide the owner/developer with guidance documents and/or actual field training in operations and maintenance procedures. The longevity and proper function of building and site components hinges on both good design and proper long-term maintenance. Land development consultants are often tasked to ensure that appropriate maintenance agreements are filed with the municipality and adequate instructions provided to the maintenance personnel.

This chapter details many of the postconstruction services commonly performed by the land development consultant including permitting and construction documentation. Further, it touches on the emerging services clients are increasingly requesting in an effort to better manage their significant land development investments. (See Figure 34.1.)

CERTIFICATES OF OCCUPANCY

A certificate of occupancy is a document of authorization from the municipality allowing a newly constructed building to be inhabited. This document certifies that the construction is in compliance with public health and safety codes and all applicable building codes. This process is important to the developer (client), as it is typically required by the lender prior to closing a loan. The certificate will not be issued until all site and building improvements have been completed and documented via the following described documents and plans.

The grading of the subject property must match an engineered site plan verbatim or within specified tolerances in the contract documents or jurisdictional guidelines. All swales, high points or low points, and the direction of runoff must be maintained with minimum or maximum grades allowed by the permitting jurisdiction. Noncompliant slopes need to be fixed and brought up to code prior to issuance of the certificate of occupancy.

Certain jurisdictions and lenders require structure location drawings—drawings verifying that the building is located correctly on the subject property. This document ensures both the lender and the municipality that the building does not cross over or sit on the lot or property lines and that it adheres to minimum building setbacks and bulk regulations, and does not encroach on proximal easements. The accuracy required for a structure location drawing varies according to local code, although it commonly ranges from 0.10 foot to 1.00 foot. Structure location drawings are considered legal documents and are signed and sealed by a licensed land surveyor.

A *final location survey* (also referred to as a *record document plan*) is required in certain jurisdictions. This is a drawing showing the location of the building and any other above-grade (visible) improvements to the property. These improvements consist of driveways, sidewalks, fences, and retaining walls. The drawing must be signed and sealed by a licensed land surveyor. Typically, the lender requires the property corners to be set. The accuracy level shown on these drawings varies according to local code, but at a minimum is equivalent to the approved plans.

A landscape certification may be required. This certification verifies that the property has the correct number of trees, accurate in terms of size and type as compared to approved plans. It ensures the lender that proper stabilization measures including sod installation and other vegetative controls have been provided according to the approved plans and issued permits.

Elevations certifications are also required in some areas. This verifies that the elevation of the first floor of the house or building is set within tolerance levels specified in the contract documents. Some municipalities require topography to be shot around the house to confirm that the conditions in the field match the proposed condition on the site plan. This is particularly important when gauging accessibility compliance. As discussed in earlier chapters, accessible routes are governed by rigid design standards and can be the subject of severe, costly lawsuits if improperly constructed and/or certified, especially in the case of projects where the Americans with Disabilities and Federal Housing Assistance Acts are applicable.

POSTCONSTRUCTION SERVICES

Postconstructions services consist of as-built surveys, bond releases, and street acceptance. All of these services can be required in a given jurisdiction and often are performed by land development consultants on behalf of clients, given their familiarity with both the project and the jurisdictional requirements.

As-Built Surveys

As-built surveys or postconstruction surveys are essential to acquire the necessary dimensions for establishing a permanent record of the location of the modifications made in the field by construction contractors. The purpose of these surveys is to present government agencies with the final opportunity to verify that the construction complies with local regulations and standards. Further, owners, occupants, tenants, and management organizations utilize the as-built information for operations and maintenance purposes. The format of the as-built survey depends on local requirements. Depending on the site conditions and jurisdiction, there are six different types of as-built surveys that can be required:

1. *Water:* All water utilities constructed are located, including dimensions of houses and structures. This allows the water utility provider to locate the utilities in the future, even under adverse weather conditions, and recover them in the event the utility gets damaged. In many municipalities the fire hydrants must be located in the North American Datum (NAD 83) so they can be input into the emergency 911 system for reference during an emergency.

2. *Sewer:* All sewer utilities constructed are located and documented, including such items as pipe and structure size, type, and slope. Comparison of these characteristics to the approved plans allows confirmation of adequate conveyance systems. This also guarantees that all sewer utilities are located within provided rights-of-way and easements.

3. *Storm drain:* All storm drain utilities constructed are located and documented, including such items as pipe and structure size, type, and slope. Comparison of these characteristics to the approved plans allows confirmation of adequate conveyance systems. This also guarantees that all storm drain utilities are located within provided rights-of-way and easements.

4. *Stormwater management facilities:* These as-built surveys are required to ensure that ponds or other stormwater management structures provide, hold, and treat the correct volume of water per the approved construction plans. This verifies that the pipes, trash racks, and risers (or other control structures) were constructed and set in place properly. It also ensures that core trenches, antiseep collars, and emergency spillways are in place as per the plans. This also guarantees that the stormwater management facility is located within the easement or designated lot.

5. *Roads:* This as-built survey guarantees that the road is built in accordance with the approved plans, has proper grades, and is in the correct location with respect to existing and proposed rights-of-way. Often, signage and other required traffic control devices are documented as well.

PRINCE GEORGE'S COUNTY
DEPARTMENT OF ENVIRONMENTAL RESOURCES
DEVELOPMENT SERVICES BRANCH
PERMITS AND REVIEW DIVISION
LANDSCAPING CERTIFICATION

1. Job Address:

Lot: Block: Subdivision:

Building Permit Number:

This is to certify to the best of my knowledge, information and belief that all landscaping on the above referenced site is in substantial accordance with the permit, approved plans, and latest revision to the Maryland-National Capital Park and Planning Commission approved site and landscaping plans dated ( ) and revised on ( ) except as noted.

Exceptions:

____

George A. Wigfield Prof. L.S. 10948

FIGURE 34.1 Typical postconstruction certification.

6. *Parking:* The as-built survey in some jurisdictions must indicate the location, dimensions, number, and type (loading spaces, handicap including vans or standard) of parking spaces as required by zoning to be shown.

In some instances, as-built surveys are a contractual requirement for the contractor. This verifies that the contractor built the project according to the design and entitles the contractor to payment. The as-built survey, also known as record drawings, is prepared on the original plans. Appropriate information is shown in a specific manner to differentiate it from the design information already on the drawings. One method is to enclose the as-built survey information in boxes and to use larger and bold lettering to distinguish it from previous design information. Many jurisdictions now require a different color, commonly red, to indicate as-built changes.

The as-built plans are considered legal documents and must be signed by a licensed surveyor, engineer, landscape architect, and/or others as required by the local ordinance. (See Figure 34.2.)

Bond Release

In general, a developer has two options in terms of bond release. The first option allows the developer to carry out an agreement that accommodates future installation and improvements, within a specified period of time, at which point a financial security, such as a letter of credit or a bond, is posted with the jurisdiction. This allows the developer to secure approval of final plans and plats prior to construc-

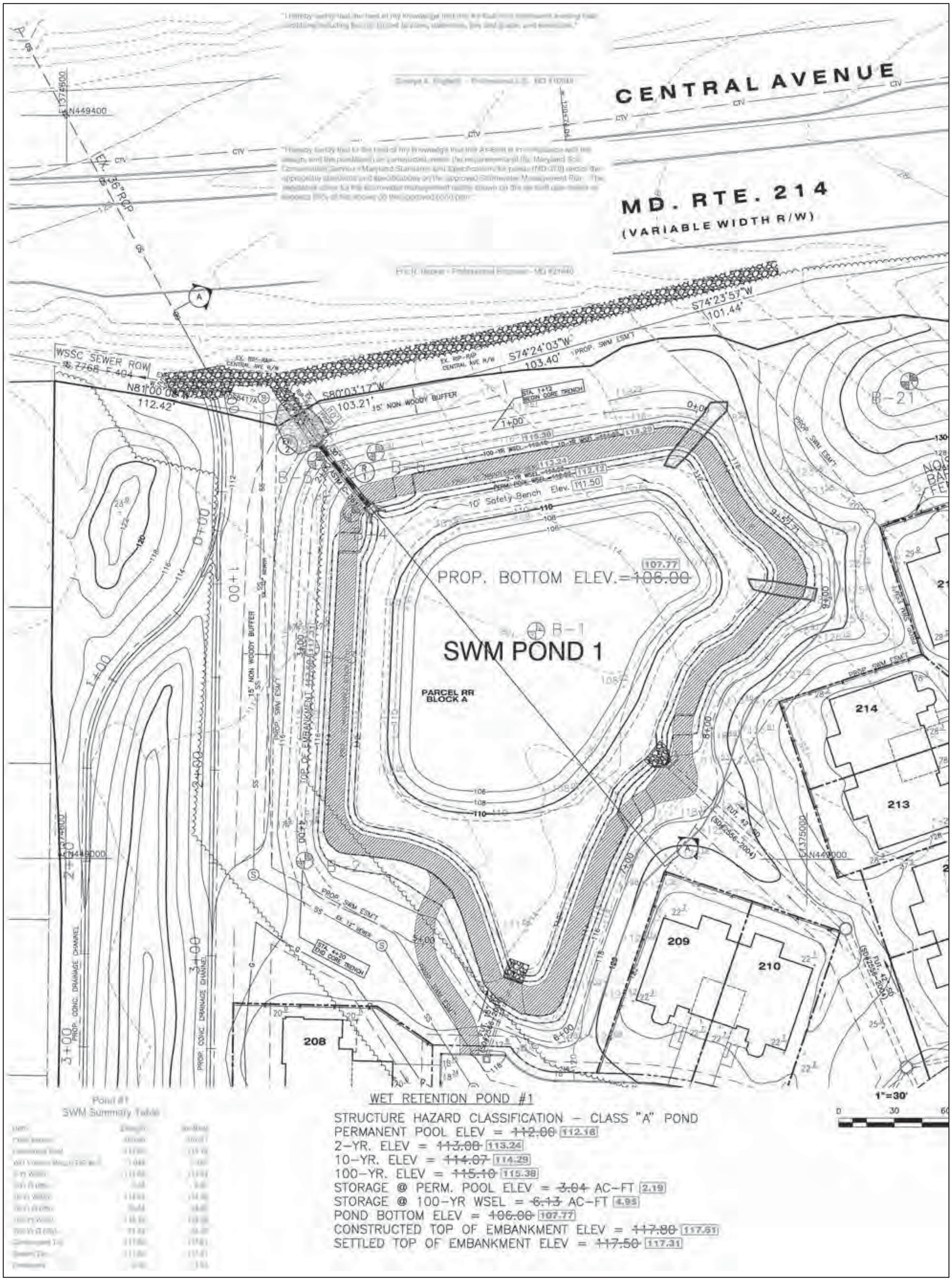

FIGURE 34.2 Typical as-built plan.

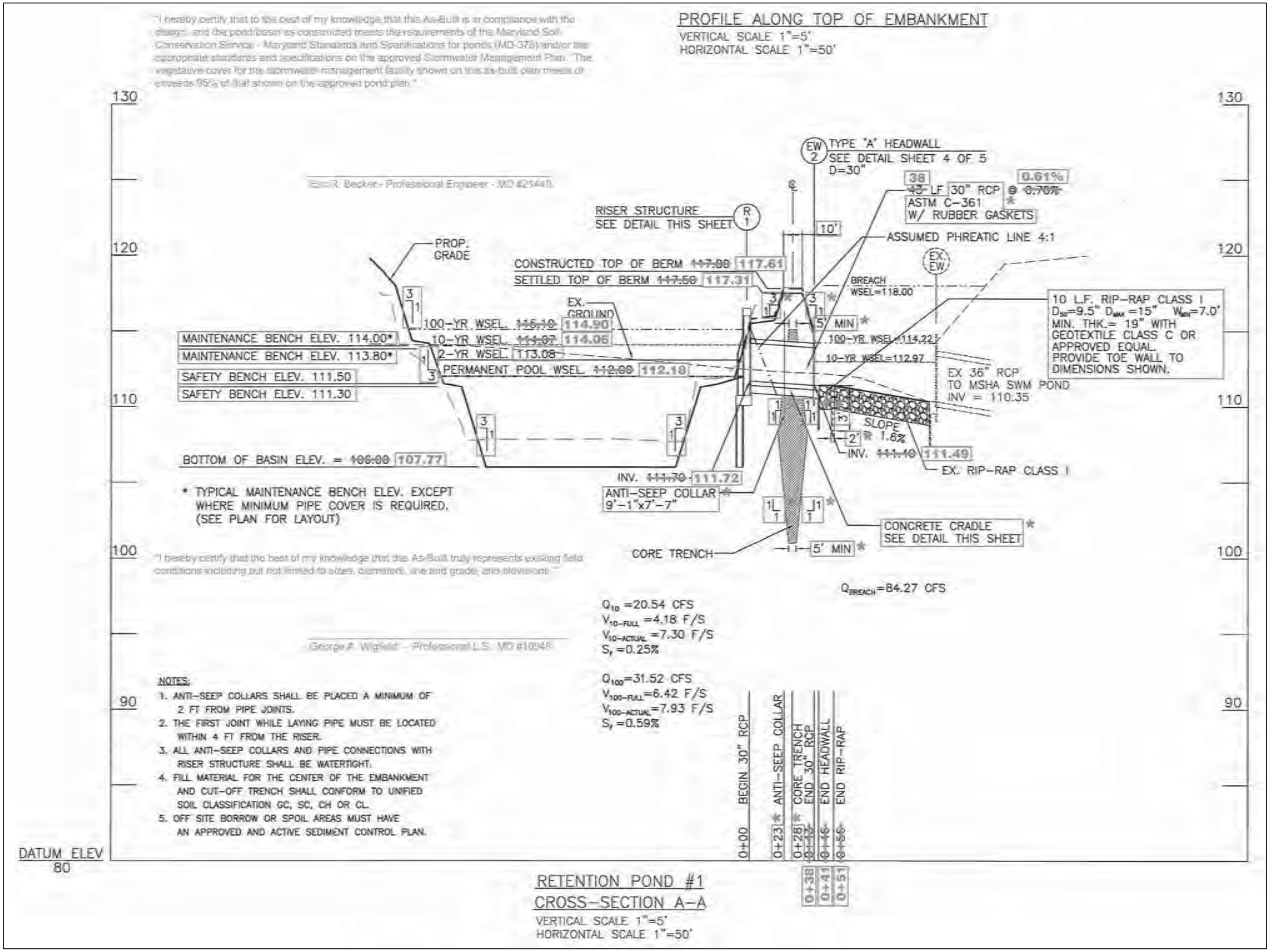

FIGURE 34.2 *(Continued)*

tion. During the construction process, occupancy permits can be obtained upon completion and inspection of the structures. Note that the public infrastructure for the development might not yet be completed and the improvements may still be under bond. It is often local practice to delay completion of the streets until all construction equipment is taken off the site. A base pavement coat may be installed, with the final top coat installed as the last step prior to bond release. This approach minimizes the potential for damage from the construction equipment or moving vans, which the developer would otherwise be responsible for repairing. Depending on the time of year, landscaping improvements may also be delayed until the start of the growing season. Where landscaping is required and included as a bonded item, the jurisdiction may allow the execution of a substitute agreement or cash escrow deposit and release the developer's primary bond.

The second option calls for completion of all improvements such as streets, utilities, and stormwater management facilities prior to the approval and recordation of the final record plats.

Street Acceptance

Street acceptance is when a newly constructed or improved public road is ready to be turned over to the municipality in perpetuity. Final paving, signage and marking, street lighting, streetside landscaping, and any utilities must be complete, correct per plan/permit, and fully located within the right-of-way. All broken, cracked, or otherwise damaged curbing, driveways, or other street components must be repaired or replaced. Finally, all right-of-way monuments must be set where required. Once the street is fully functional, it can be legally accepted into the public street system; at this time, all maintenance responsibilities transfer to the public entity.

Operations and Maintenance (O&M)

Construction and final as-builts no longer represent the conclusion to land development consulting services: the long-term success of land development projects is dependent on proper operations and maintenance. Who better to ensure and implement adequate O&M procedures than the designers who developed the building and infrastructure systems and the surveyors who have documented (in most cases, electronically) the construction? Whether it is a commercial development managed entirely by a professional management group, a large residential or master planned community managed by one or more homeowner's associations (HOAs), or an individual homeowner taking care of his or her property, O&M responsibilities and procedures must be clearly delineated and defined in order to ensure that the design intent of constructed facilities is achieved.

Proper O&M procedures involve three distinct steps:

1. *Identify O&M responsibility:* Often tied to ownership and/or location of the facility, it is important to *understand who is responsible* for carrying out long-term maintenance of each building and site component.

2. *Provide O&M procedures:* Depending on the specific facility or infrastructure system, maintenance procedures can vary widely. At a minimum, *clarify what needs to be done:* prepare directions for maintenance activities and a recommended schedule for completion. Disseminate this information to responsible parties.

3. *Develop management tools to facilitate proper O&M:* Accurate, informative mapping is vital to successful O&M. Maps often contain the answer to the first step in O&M—who is responsible?—and aid in the second step by providing a means of tracking or recording O&M processes. The land development consultant who has been part of the design and construction process likely has all the relevant information spatially referenced. It is merely a matter of taking this process one step further to *package the information in a manner that is useful to the designated maintenance personnel.* Whether it is tying the map to an online database or providing hard copies in the form of a comprehensive map book or atlas, the information must be readily available and in keeping with the management system employed by the client/developer.

Many jurisdictions require certain components of the O&M program to be specified on the plans and plats—namely, maintenance responsibility: is the noted facility publicly or privately maintained? While the presence or lack of an easement is often a good indicator of maintenance responsibility, this is helpful only if the map or drawing showing the easement is available for viewing when ownership or maintenance responsibility is brought into question. Easements are not visible in the field; signage or other physical indicators are required in order to assess maintenance responsibility unless refined maps, as discussed, are available. Further, "privately maintained" can be a vague description, particularly when multiple utility providers, HOAs, or other management entities are involved. For instance, a private utility pole might belong to the electric company, the cable company, the telephone company, or an HOA; without a field indicator or accurate mapping, it is an iterative process to determine responsibility. (Refer to Figures 34.3 and 34.4.)

Occasionally jurisdictions do require maintenance instructions for certain facilities on plans or plats—stormwater management, landscaping, and on-site wastewater treatment facilities, when specified, typically have maintenance criteria included on the plan. This will become increasingly common as low-impact development and sustainable design continue to become mainstream approaches to large- and small-scale development. In fact, many of the green building certification programs—U.S. Green Building Council's LEED systems and National Association of Home Builders' Green Guide for Homes—recognize and award credits/points for O&M training/education, monitoring, and post-construction facility optimization. Thus, by providing clear

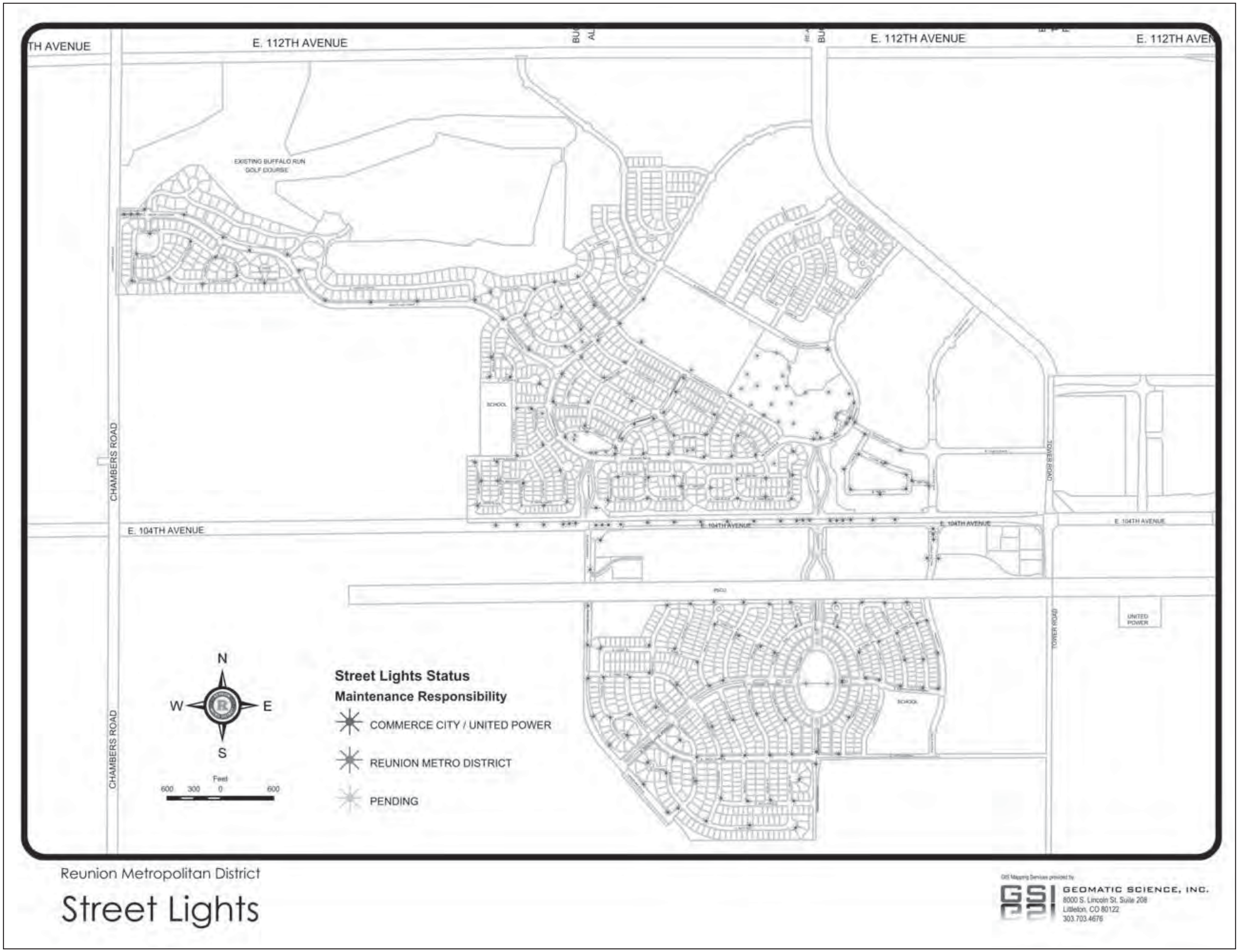

FIGURE 34.3 Reunion Metropolitan District Maintenance Responsibilities. (Geomatic Science “Reunion Metropolitan District: Maintenance Responsibilities”)

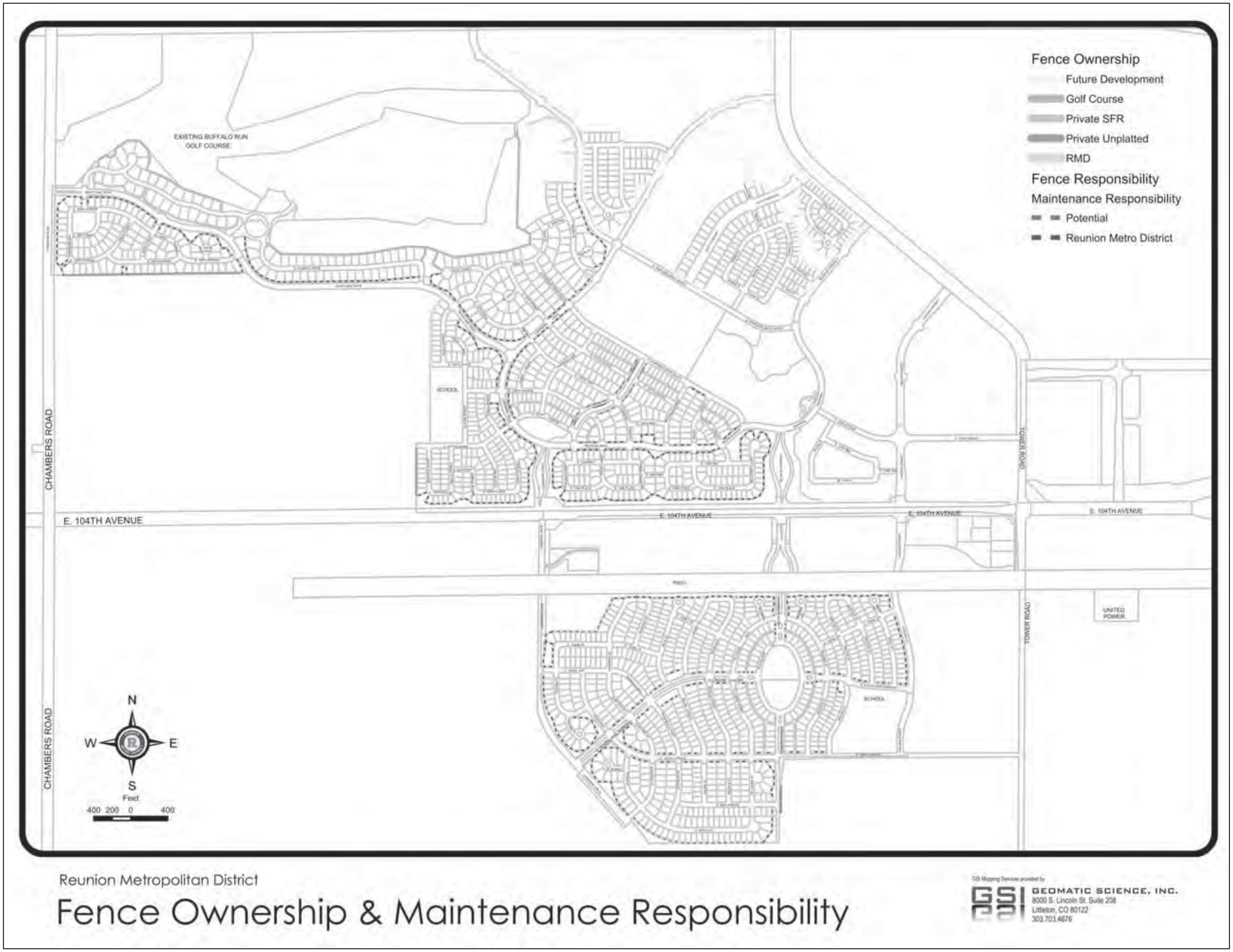

FIGURE 34.4 Reunion Metropolitan District Fence Ownership and Responsibility. (Geomatic Science "Reunion Metropolitan District: Fence Ownership and Responsibilities")

operating instructions, conducting maintenance staff training and occupant education, and disseminating accurate facility information (inherently collected during the process), land development consultants can continue to aid clients/developers in meeting their green building goals.

Facility management tools such as interactive maps are easier to develop and increasingly common, given the advances in computer-aided design and drafting (CADD) including smart drawings, building information modeling (BIM), and GIS technology. The ability to link spatially referenced data to interactive maps, customized databases, online Web resources and query systems—to name a few options—is merely the beginning of life cycle project management. This final deliverable may take many forms (digital or hard copy, manual or map book) and is created during the course of design and construction as information is developed, gathered, and assembled. This final packaging step is a means of consolidating all the design and surveying efforts into a single useful tool—an accurate record of the facility, its systems, its O&M requirements, and a means of tracking or logging activity related to successful function of the building and infrastructure systems.

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Part VIII

Technical Appendices

APPENDIX A

AERIAL MAPPING AND SURVEYING

David F. Maune, PhD, PSM, GS, PS, CP, CFM

INTRODUCTION TO GEOSPATIAL DATA

Spatial data deals with location, shapes, and the relationships among features (topology). Site civil drawings, survey drawings, and architectural drawings are examples of spatial data normally compiled with computer-aided design and drafting (CADD) technology. Accuracies are typically depicted in relative terms—for example, boundary surveys relative to survey corners for which the geographic coordinates may be unknown in an absolute sense. Pairs of *x-y* coordinates may be referenced to an arbitrary origin, and accuracies are typically relative—for example, estimated as *n* parts per million of the distance surveyed from one point to the next. The curvature of the earth is often a negligible factor, and the rules of plane geometry typically apply.

Geospatial data refers to spatial data for which geographic coordinates are known in an absolute sense, that is, the spatial dataset is *georeferenced* to true ground coordinates. The curvature of the earth is important, and the rules of spherical geometry typically apply. Positioning is relative to geodetic data, using control surveys having geodetic *network accuracy,* rather than *local accuracy* relative to an arbitrary origin. Geospatial data is georeferenced as 2-D or 3-D coordinates of points on, above, or below a mathematical model of the earth (ellipsoid). Horizontal positions may be expressed in terms of *geographic coordinates,* that is, longitude (λ) east or west of the Greenwich Meridian and latitude (ϕ) north or south of the equator. For land development general planning purposes, horizontal positions are normally expressed as 2-D rectangular coordinate pairs, that is, easting (x) and northing (y) coordinates relative to a *horizontal datum* and coordinate system origin (where x and y coordinates are zero) normally defined by the State Plane Coordinate System (SPCS). For detailed planning purposes, a z value is added to each x-y coordinate pair in order to define elevations relative to a *vertical datum* and origin where the elevation (z value) is zero. These 3-D coordinates may be obtained from ground surveying (as described in detail in other chapters) or aerial surveying and mapping as described in this appendix, to include photogrammetry and light detection and ranging (LiDAR). These 3-D coordinates could also be obtained from various forms of geographic information systems (GIS).

In some states, those engaged in aerial mapping and surveying require professional licensure (e.g., photogrammetric surveyors), much like professional land surveyors and professional engineers. The reason for this is that state definitions for the "practice of land surveying" require licensure for those who determine authoritative positions, coordinates, and topography for which an unqualified practitioner could adversely impact public safety and welfare, regardless of whether such data are produced by land surveyors or aerial surveyors. A few states even require those producing GIS datasets to be licensed, even though they generally use, overlay, and/or reformat data produced by others rather than provide authoritative positioning.

Types of Geospatial Data

This section is important because failure to understand the different types of geospatial data could cause the wrong data to be requested, resulting in subcontracts for data unsuitable for its intended purpose and/or requiring additional expenses to correct misunderstandings.

Raster Data and Vector Data. *Raster data* consists of pixels or grid cells of uniform resolution. Digital images are raster data, as are maps or engineer drawings scanned at

500 or 1000 dots per inch (dpi), for example. A *pixel* (picture element) is the smallest indivisible element of a digital image. One pixel of a LANDSAT satellite multispectral image equates to a 30-meter by 30-meter square area on the ground; 1 pixel of a standard USGS Digital Orthophoto Quarter-Quad (DOQQ) covers a 1-meter by 1-meter square area, and 1 pixel of a high-resolution digital orthophoto typically produced specifically for a land development project might cover a 6-inch by 6-inch area on the ground. Such images are referred to as having 30-meter, 1-meter, or 6-inch pixel resolution, respectively. However, users can typically see features that are much smaller than the pixel resolution; for example, road paint stripes, 4 inches wide, can often be seen on DOQQs with 1-meter pixel resolution. The resolution of scanned documents is referred to in terms of dpi. Raster images can be displayed on the computer at different scales, to the point where *pixel breakdown* occurs and individual pixels are visible, but zooming in does not improve the accuracy of such raster data.

Somewhat different from a pixel, a raster *grid cell* is one element of a more detailed image or surface, simplified for cost and convenience using user-defined grid-spacing criteria. Square grids are commonly defined to reduce the computer file storage requirements for large geospatial datasets. For example, whereas it might be desirable to utilize digital orthophotos with 6-inch pixel resolution as base maps, larger grid cells of 1 meter, 10 meters, 50 meters, and larger are often preferred to display soil types, geology, vegetation classification, land use/land cover, and natural features that do not need to be precisely depicted. Similarly with elevation data, whereas it might be necessary to collect randomly spaced LiDAR data with average point density of 4 points per square meter in order to maximize the potential for penetrating vegetation to map the bare-earth terrain beneath the trees, the file sizes are very large for recording *x-y-z* coordinates for millions/billions of points, and the analysis/display software is more expensive. File sizes are much smaller when using a digital elevation model (DEM) grid spacing of 1 meter (are larger) for which *x-y* coordinates do not need to be individually stored and only the average *z* value is stored for each square grid cell. Instead of complex horizontal coordinates, grid cells are tracked by sequential rows and columns.

Vector data consists of 2-D (*x-y*) or 3-D (*x-y-z*) coordinates defining the locations of point, line, and area features. Related terms include *nodes, vertices, shape points, arcs, degenerate lines, line strings, line chains, edges, polygons,* and other terms that have their own definitions. Vector data may be displayed on a computer with different colors, line styles (solid, dashed, dotted, etc.), line weights (thicknesses), and symbols. Vector lines and curves are normally smooth, while grid cell raster data have a stair-step appearance, especially when zoomed-in to view the raster data at a large scale. CADD drawings are a form of vector data, as are survey data with points having 2-D or 3-D coordinates, and lines having distances and bearings.

Merged raster/vector data is now common with modern GISs. Raster images are more understandable to humans, but attributed vector data is more intelligible to computers. The merger of raster and vector data (normally the overlay of vector data on top of raster images) allows the best of both worlds. The raster data normally serves as a base map for overlay of vector GIS data.

Descriptive Data and Map Annotations. *Descriptive data* more fully describes the geospatial data. *Attributes* describe the various point, line, and area features, such as length, diameter, manufacturer, model, serial number, material composition, burial depth, and installation data of a utility feature. Often, feature attribute codes are used to describe diverse feature types. Alphanumeric textual data or attributes are often stored in relational databases, and selected items from the database may be displayed on maps. Descriptive databases can be managed separately from geospatial data; for example, a tax assessor's database may be linked to a county's parcel maps but maintained separately and confidentially from spatial databases available to the general public.

Annotations are map symbols or alphanumeric labels such as route numbers, elevations, or names of towns, streets, rivers, or mountains placed on maps. On digital maps, annotations are normally key-entered, then stored with coordinates for the beginning, center, or ending of the annotation and/or with other rules for placement and orientation, text fonts, and special characters and symbols of various sizes.

Planimetric Maps and Topographic Maps. *Planimetric maps* display the horizontal positions of natural and man-made features and boundary lines. Planimetric data is displayed in two dimensions only. If maps do not display elevation data with contour lines or an alternative method, they are planimetric maps. In a computer, planimetric data is treated as 2-D files having *x-y* coordinates. Digital orthophotos are a form of planimetric map where no elevation data is presented. Planimetric maps and planimetric data normally form the base maps for overlay of other data required for a land development project.

When people refer to *planimetrics,* they normally mean planimetric data that can be seen and mapped horizontally, typically from stereo photogrammetry described later. Planimetrics include hydrographic features (e.g., rivers, lakes, and shorelines), transportation features (e.g., road/highway edge of pavement, bridges, railroad tracks, and airport runways and taxiways), man-made features (e.g., building footprints, transmission lines, fire hydrants), and other features that can be seen from aerial photography. The term *planimetrics* does not normally include boundary lines and underground utilities that cannot be mapped with stereo aerial photography, even though they can be surveyed and georeferenced on planimetric maps. Similarly, a *plan view* shows the horizontal location of features as though looking straight down from infinity.

Topographic maps display both the horizontal positions of natural and man-made features and boundary lines as well as elevation data (normally contour lines). In a computer, topographic data may be 3-D files having *x-y-z* coordinates for individual points or line strings, or they may be different forms of 2-D files with at least one file including contour lines with elevation attributes. Topographic data and topographic surveys normally end at the edge of water bodies, but they often include the elevation of a lake.

Both planimetric data and topographic data are produced by field surveying, photogrammetric mapping, and/or remote sensing. Topographic data is also produced by new remote sensing technologies, especially LiDAR, for which the intensity images approximate an orthophoto image and for which lidargrammetry can be used to generate 2-D or 3-D breaklines. Whether produced from photogrammetry or lidargrammetry, breaklines are linear features that describe a change in the smoothness or continuity of a surface. The two most common forms of breaklines are as follows:

- A *soft breakline* ensures that known *z* values along a linear feature are maintained (e.g., elevations along a pipeline, road centerline, or drainage ditch) and that linear features and polygon edges are maintained in a triangulated irregular network (TIN) surface model, by enforcing the breaklines as TIN edges. They are generally synonymous with 3-D breaklines because they are depicted with series of *x-y-z* coordinates. Somewhat rounded ridges (road crowns) or the trough of a drain may be collected using soft breaklines.

- A *hard breakline* defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are 3-D breaklines, they are often 2-D breaklines because features such as shorelines and building footprints are normally depicted with series of *x-y* coordinates only, often digitized from digital orthophotos that include no elevation data.

Mass points are irregularly spaced points, each with *x-y* location coordinates and *z* value, typically (but not always) used to form a TIN. When generated manually—by a photogrammetrist, for example—mass points are ideally chosen to depict the most significant variations in the slope or aspect of TIN triangles. However, when generated automatically—for example, by photogrammetric automated image correlation, LiDAR, or IFSAR—mass point spacing and pattern depend on the characteristics of the technologies used to acquire the data and postspacing criteria selected by the operator.

Digital Elevation Models (DEMs). DEMs have at least three different meanings to different users. For some, DEM is a generic term for digital topographic and/or bathymetric data in all its various forms. For the U.S. Geological Survey (USGS), a DEM is a standard form of elevation dataset at regularly spaced intervals in *x* and *y* directions georeferenced in Universal Transverse Mercator (UTM) coordinates (with uniform 30-meter or 10-meter grid spacing) or geographic coordinates (with uniform 1-arc-second or ⅓-arc-second grid spacing); some data is now available in ⅑-arc-second, approximately 3-meter spacing at the equator. For others in the United States, a DEM has *z* values at regularly spaced intervals in *x* and *y* directions, but with alternative specifications, such as narrower grid spacing and State Plane coordinates. DEMs always imply elevation of the terrain (bare-earth *z* values) devoid of vegetation and man-made features, as opposed to digital surface models (DSMs) that include the elevations of treetops, rooftops, towers, and other features raised above the terrain. In Europe, DEMs are considered to be synonymous with digital terrain models (DTMs), but in the United States DTMs include irregularly spaced mass points and/or breaklines where the slope changes, thereby depicting the true shape of the terrain more accurately than a gridded DEM. For more information on this subject, see *Digital Elevation Model Technologies and Applications: The DEM Users Manual,* published in 2007 by the American Society for Photogrammetry and Remote Sensing (ASPRS). DEMs, DTMs, and DSMs are efficiently used for computer analysis and display of the topographic surface.

Contours. Contours are lines of equal elevation. They are intended exclusively for human interpretation and have little if any value for computer analyses of the terrain. Contours have traditionally been produced by stereo photogrammetric compilation, where the operator can see the breaklines (where the slope changes) and can manually shape the contour lines so that they are aesthetically pleasing. When manually compiling maps using photogrammetry, the compiler also shapes contours (according to established rules) where they cross streams and roads.

When contours are generated automatically from DEMs, they are not as aesthetically pleasing. A DEM has no way of knowing where a breakline exists between DEM points and, therefore, can't automatically shape the contours to depict streams, roads, retaining walls, and so on, correctly. Breaklines are added to correct for this limitation. It is much simpler to convert contours into DEMs (for computer analysis of the terrain) than to convert DEMs into contours (for visual analysis of the terrain).

Digital Orthophotos. A digital orthophoto has the image qualities of an aerial photograph but the metric properties of a map. A digital orthophoto is a digital image from a perspective photo or image, corrected by an orthorectification process so as to remove *tilt displacement* (caused by the roll, pitch, and yaw of the aircraft in flight) and *relief displacement* (caused by the perspective view of the aerial photograph, which causes taller objects to appear larger and closer than they really are to the camera). Digital images are produced either by acquiring the aerial images with a digital camera or by scanning aerial film. Processes for removing tilt displacement and relief displacement are explained in the section on photogrammetry later in this chapter.

NATIONAL SPATIAL DATA INFRASTRUCTURE (NSDI)

Framework Data

The NSDI is defined as the technologies, policies, and people necessary to promote sharing of geospatial data throughout all levels of government, the private and nonprofit sectors, and the academic community. The NSDI *framework* is a collaborative effort to create a widely available source of basic geographic data. It provides the most common data themes geographic data users need, as well as an environment to support the development and use of these data. The framework represents "data you can trust"—the best available data for an area, certified, standardized, and described according to a common standard.

The NSDI framework provides a foundation on which organizations can build by adding their own detail and compiling other datasets. Its key aspects are: (1) seven themes of digital geographic data that are commonly used, including geodetic control, orthoimagery, elevation, transportation, hydrography, governmental units, and cadastral information; (2) procedures, technology, and guidelines that provide for integration, sharing, and use of this data; and (3) institutional relationships and business practices that encourage the maintenance and use of the data.

National Spatial Reference System (NSRS)

The NSRS is a consistent coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States, and how these values change with time. The NSRS comprises the following:

1. The National CORS, a set of global positioning system (GPS) continuously operating reference stations (CORS) meeting the highest standards for defining the geodetic datum.
2. A network of permanent survey monuments including the Federal Base Network (FBN), Cooperative Base Network (CBN), and User Densification Network (UDN).
3. A consistent, accurate, and up-to-date national shoreline.
4. A set of accurate models describing dynamic geophysical processes that affect spatial measurements.

The NSRS provides a highly accurate, precise, consistent geographic framework throughout the United States. It is the foundation for the NSDI and a significant national resource. It includes hundreds of thousands of geodetic control monuments and benchmarks that have been surveyed relative to our horizontal and vertical datums (i.e., NAD 83 and NAVD 88). As per the NSDI framework motto, the NSRS represents survey control "data you can trust"—the best available survey data for any area within the United States. It's accurate, it's readily available on the Web, it's simple to use, and it's free. NSRS data should be used as the foundation for any land development survey project.

To locate the most suitable NSRS survey monuments for any project area, visit the National Geodetic Survey (NGS) home page at www.ngs.noaa.gov, then click on "Data Sheets." Under "Search the NGS DataBase and Retrieve Data Sheets," select either "radial search" or "rectangular search." Under "radial search," enter the latitude and longitude of the center of the land development project area or the estimated geographic coordinates of the local network control point to be surveyed, plus the circular search radius in miles, up to 20 miles maximum. Alternatively, under "rectangular search," enter the min-max values for the latitude and longitude of the rectangle surrounding the project site or the local network control point to be surveyed. NGS data sheets will be listed for all NSRS monuments within the search area so that the best monuments can be selected for extension of subsequent control. If more than 100 NSRS control points exist within the specified area, the user needs to subdivide the rectangular search area or narrow the radial search area in order to fit below the 100 maximum data sheets that can be printed from the website.

Last, the user will be asked to select survey control points in one of three categories: (1) any horizontal and/or vertical control point (surveyed by any method—conventional or GPS), (2) any horizontal control points only (surveyed by any method—conventional or GPS), and (3) GPS sites only.

FEDERAL GEOGRAPHIC DATA COMMITTEE (FGDC) ACCURACY STANDARDS

For a half century, nearly all maps were produced in accordance with the National Map Accuracy Standard (NMAS) published in 1947. But the NMAS was replaced in 1998 by the FGDC Geospatial Positioning Accuracy Standards for digital geospatial data. It is important for land development surveyors and engineers to understand the differences between the new and the old standards. This subsection first summarizes the old standards before comparing them with the new standards.

National Map Accuracy Standard (NMAS)

According to the NMAS (Bureau of the Budget, 1947), horizontal and vertical accuracy of maps are defined as follows:

- For maps produced at a scale of 1:20,000 and larger (which includes most land development projects), "not more than 10 percent of the points tested shall be in error by more than 1⁄30 inch, measured on the publication scale. . . . These limits of accuracy shall apply in all cases to positions of well defined points only. 'Well defined' points are those that are easily visible or recoverable on the ground, such as the following: monuments or markers, such as bench marks, property boundary monuments, intersections of roads, railroads, etc.; corners of large buildings or structures (or center points of small buildings), etc. In general what is 'well defined' will also be determined by what is plottable on the scale of the map within 1⁄100 inch." At map scale, the Circular Map

Accuracy Standard (CMAS) equals 1/30th of an inch; at ground scale, the CMAS equals 1/30th of an inch divided by the map scale. For example, DOQQs compiled at 1 in = 1,000 ft have a CMAS of 1/30th of an inch on the map or 33.3 ft on the ground."

- "Vertical accuracy, as applied to contour maps on all publication scales, shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval. In checking elevations taken from the map, the apparent vertical error may be decreased by assuming a horizontal displacement within the permissible horizontal error for a map of that scale." For example, the Vertical Map Accuracy Standard (VMAS) equals one-half the contour interval on the map, or 1.0 foot in ground elevation if the contour interval is 2 feet.

Both the CMAS and the VMAS are standards at the 90 percent confidence level, but these NMAS errors do not necessarily follow a normal distribution—that is, there are no limits to the size of the errors that exceed the CMAS or VMAS. The NMAS is now obsolete for use with digital geospatial data.

Geospatial Positioning Accuracy Standards (GPAS)

With digital data, the geospatial data community recognized that the NMAS standards were inappropriate because the scale and contour interval of a digital map could be changed with the click of a computer mouse, without changing the underlying accuracy of the data. Just because one can easily zoom in on GIS data and view the data at high resolution does not mean that the data suddenly gets more accurate.

In 1990, the American Society for Photogrammetry and Remote Sensing (ASPRS) published the ASPRS standards for Large Scale Maps (ASPRS, 1990). These ASPRS 90 standards were modified subsequently by the Federal Geographic Data Committee (FGDC) in the FGDC Geospatial Positioning Accuracy Standards (GPAS), published in 1998, which officially replaced the NMAS for digital geospatial data. Although the GPAS has three parts, almost everyone refers to Part 3—the NSSDA—when referring to the GPAS.

- Part 1: Reporting Methodology (FGDC, 1998a)
- Part 2: Standards for Geodetic Networks (FGDC, 1998b)
- Part 3: National Standard for Spatial Data Accuracy (NSSDA)(FGDC, 1998c)

Part 1: Reporting Methodology. Reference FGDC-STD-007.1-1998 at www.fgdc.gov/standards/documents/standards/chapter1.pdf.

Part 1 provides a common methodology for reporting the accuracy of horizontal and/or vertical coordinate values for clearly defined features where the location is represented by a single-point coordinate, either 2-D or 3-D. Examples are survey monuments; prominent landmarks such as church spires, standpipes, radio towers, tall chimneys, and mountain peaks; and targeted photogrammetric control points. It provides the means to compare directly the accuracy of coordinate values obtained by one method (e.g., a cartographically derived value) with that obtained by another method (e.g., a GPS geodetic network survey) for the same point. This helps the users to know not only the coordinate values but also the accuracy of those coordinate values, so they can decide which coordinate values represent the best estimate of the true value for their applications.

According to FGDC, 1998a, horizontal and vertical accuracy are to be reported in ground distances at the 95 percent confidence level, as follows:

- Horizontal: "The reporting standard in the horizontal component is the radius of a circle of uncertainty, such that the true or theoretical location of the point falls within that circle 95-percent of the time." The National Standard for Spatial Data Accuracy (NSSDA) refers to this horizontal accuracy component as "Accuracy_r."
- Vertical: "The reporting standard in the vertical component is a linear uncertainty value, such that the true or theoretical location of the point falls within ± of that linear uncertainty value 95-percent of the time." The NSSDA refers to this vertical accuracy component as "Accuracy_z."

Furthermore, accuracy is to be reported in terms of local accuracy or network accuracy.

- "The *local accuracy* of a control point is a value that represents the uncertainty in the coordinates of the control point relative to the coordinates of other directly connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual accuracy values between this control point and other observed control points used to establish the coordinates of the control point." (For practical purposes, *local accuracy* can be considered the equivalent of *relative accuracy,* defined in other FGDC standards as "point-to-point accuracy.")
- "The *network accuracy* of a control point is a value that represents the uncertainty in the coordinates of the control point with respect to the geodetic datum at the 95-percent confidence level. For NSRS network accuracy classification, the datum is considered to be best expressed by the geodetic values at the Continuously Operating Reference Stations (CORS) supported by NGS. By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero." (For practical purposes, *network accuracy* can be considered the equivalent of *absolute accuracy,* defined in other FGDC standards as "accuracy

stated with respect to a defined datum or reference system.")

Part 2: Standards for Geodetic Networks. Reference FGDC-STD-007.2-1998 at www.fgdc.gov/standards/documents/standards/chapter2.pdf.

Part 2 (FGDC, 1998b) provides a common methodology for determining and reporting the accuracy of horizontal and vertical coordinate values for geodetic control points represented by survey monuments such as brass disks and rod marks. It provides a means to compare directly the accuracy of coordinate values obtained by one method (e.g., a classical line-of-sight traverse) with the accuracy of coordinate values obtained by another method (e.g., a GPS geodetic network survey) for the same point.

According to FGDC, 1998b, geodetic control surveys are usually performed to establish a basic control network (framework) from which supplemental surveying and mapping work is performed (e.g., for land development). Geodetic network surveys are distinguished by use of redundant, interconnected, permanently monumented control points that constitute the framework for the NSRS or are often incorporated into the NSRS. Such surveys must be performed to far more rigorous accuracy and quality assurance standards than those for control surveys for general engineering or construction. However, geodetic control surveys are required for controlling interstate transportation corridors (e.g., highways, pipelines, and railroads), long-span bridge construction alignment, geophysical studies, and structural deformation monitoring of dams, buildings, and similar facilities.

The NSRS supports both local accuracy and network accuracy. Local accuracy is best adapted to check relations between nearby control points; for example, a surveyor checking closure between two NSRS points is mostly interested in a local accuracy measure. On the other hand, someone constructing a GIS or LIS often needs some type of positional tolerance associated with a set of coordinates. Network accuracy measures how well coordinates approach the error-free datum. To establish the network accuracy of a control point, it is not necessary to connect directly to a CORS; however, it is necessary that the survey be connected properly to existing NSRS control points with established network accuracy values.

Part 3: National Standard for Spatial Data Accuracy (NSSDA). Reference FGDC-STD-007.3-1998 at www.fgdc.gov/standards/documents/standards/chapter3.pdf.

The NSSDA (FGDC, 1998c) implements a statistical and testing methodology for estimating the positional accuracy of points on maps and in digital geospatial data, with respect to georeferenced ground positions of higher accuracy. The NSSDA applies to fully georeferenced maps and digital geospatial data, in either raster, point, or vector format, derived from sources such as aerial photographs, satellite imagery, and ground surveys. Contrary to the National Map Accuracy Standard, which is now obsolete, the NSSDA does not define threshold accuracy values. Producing agencies and users must identify acceptable accuracies for their applications. Data and map producers must determine what accuracy exists or is achievable for their data and report it according to the NSSDA.

According to FGDC, 1998c, "Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product."

The NSSDA uses root-mean-square error (RMSE) to estimate positional accuracy. RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of high accuracy for identical points.

Well-established procedures (e.g., field surveys or photogrammetry with fully analytical aerial triangulation) report accuracy as follows: "Compiled to meet ____ (meters, feet) horizontal accuracy at 95% confidence level; compiled to meet ____ (meters, feet) vertical accuracy at 95% confidence level."

New or questionable procedures (e.g., LiDAR or photogrammetry without fully analytical aerial triangulation) should be tested with accuracy reported as follows: "Tested (meters, feet) horizontal accuracy at 95% confidence level; tested ____ (meters, feet) vertical accuracy at 95% confidence level."

When determined to be required, accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. Horizontal accuracy should be tested by comparing the planimetric coordinates of well-defined points in the dataset with coordinates of the same points from an independent source of higher accuracy. A well-defined point represents a feature for which the horizontal position is known to a high degree of accuracy and position with respect to the geodetic datum; for the purpose of accuracy testing, well-defined points must be easily visible or recoverable on the ground, on the independent source of higher accuracy, and on the mapping or GIS product itself. Vertical accuracy should be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy; graphic-contour data and digital topographic data may not contain well-defined points; therefore, the accuracy of a DEM is computed by a comparison of linearly interpolated elevations in the DEM with corresponding known elevations of checkpoints of higher accuracy. ASPRS, 2007, provides guidance on the selection of appropriate vertical checkpoints as well as pitfalls to be avoided in vertical accuracy testing.

TABLE A.1 NMAS and NSSDA Horizontal Accuracy Equivalencies

MAP SCALE OR COMPILATION SCALE	NMAS, CMAS AT 90% CONFIDENCE LEVEL	NSSDA, ACCURACY$_r$ AT 95% CONFIDENCE LEVEL	RMSE$_r$
1 in = 50 ft or 1:600	1/30 in = 1.67 ft ground distance	1.90 ft ground distance	1.10 ft ground distance
1 in = 83.3 ft or 1:1000	1/30 in = 2.78 ft ground distance	3.17 ft ground distance	1.83 ft ground distance
1 in = 100 ft or 1:1200	1/30 in = 3.33 ft ground distance	3.80 ft ground distance	2.20 ft ground distance
1 in = 200 ft or 1:2400	1/30 in = 6.67 ft ground distance	7.60 ft ground distance	4.39 ft ground distance

Normally, a minimum of 20 checkpoints should be tested; then the 95 percent confidence level allows 1 point to fail the threshold given in product specifications.

For horizontal accuracy testing, the radial RMSE ($RMSE_r$) is determined; then $Accuracy_r = 1.7308 \times RMSE_r$, where $RMSE_r = \sqrt{RMSE_x^2 + RMSE_y^2}$.

If horizontal errors are believed to have a normal distribution, a conversion can be made between the NMAS's Circular Map Accuracy Standard (CMAS) and NSSDA's $RMSE_r$ and $Accuracy_r$ as follows:

- $CMAS = 1.5175 \times RMSE_r$
- $Accuracy_r = 1.1406 \times CMAS$

Table A.1 provides examples of equivalent horizontal accuracy standards, comparing the NMAS accuracy thresholds (90 percent confidence level) for specified map scales with comparable accuracy reported per NSSDA terminology in terms of the $RMSE_r$ and $Accuracy_r$ (horizontal radial accuracy at the 95 percent confidence level).

For vertical accuracy testing, the vertical RMSE ($RMSE_z$) is determined; then $Accuracy_z = 1.9600 \times RMSE_z$. If elevation errors are believed to have a normal distribution, a conversion can be made between the NMAS's Vertical Map Accuracy Standard (VMAS) and NSSDA's $RMSE_z$ and $Accuracy_z$ as follows:

- $VMAS = 1.6449 \times RMSE_z$
- $Accuracy_z = 1.1916 \times VMAS$
- $\text{Contour Interval} = 3.2898 \times RMSE_z$

Table A.2 provides examples of equivalent vertical accuracy standards, comparing the NMAS accuracy thresholds (90 percent confidence level) for specified contour intervals with comparable accuracy reported per NSSDA terminology in terms of $RMSE_z$ and $Accuracy_z$ (vertical accuracy at the 95 percent confidence level).

It should be noted that the NMAS/NSSDA equivalencies in Tables A.1 and A.2 can be made only by assuming that all errors have a normal distribution. In fact, the NMAS never made this assumption, and 10 percent of the errors are allowed to exceed the threshold values at the 90 percent confidence level, regardless of size. The NMAS outliers could presumably be very large errors, whereas the NSSDA outliers would presumably be relatively small, or else they would skew the RMSE calculations disproportionately. Because the remote sensing community knows that vertical errors in

TABLE A.2 NMAS and NSSDA Vertical Accuracy Equivalencies

CONTOUR INTERVAL AT WHICH COMPILED	NMAS, VMAS AT 90% CONFIDENCE LEVEL	NSSDA, ACCURACY$_z$ AT 95% CONFIDENCE LEVEL	RMSE$_z$
6 in	3 in	3.57 in or 9.08 cm	1.82 in or 4.63 cm
1 ft	6 in	7.15 in or 18.16 cm	3.65 in or 9.27 cm
2 ft	12 in	14.30 in or 36.32 cm	7.30 in or 18.53 cm
5 ft	30 in	35.75 in or 90.80 cm	18.24 in or 46.33 cm

bare-earth LiDAR datasets sometimes do not follow a normal error distribution in vegetated terrain where the vegetation filtering process does not necessarily follow a normal error distribution, alternative procedures for testing and reporting LiDAR data are documented in ASPRS, 2007, consistent with guidelines from the National Digital Elevation Program (NDEP) and ASPRS LiDAR accuracy reporting guidelines.

AERIAL MAPPING DISCIPLINES

CADD drawings and GIS databases, described in other chapters and appendices, are often based on source data using disciplines/technologies described here.

- A basic understanding of geodesy is required for larger land development projects, because geodesy makes maps accurate.
- A basic understanding of photogrammetry is required for aerial image acquisition and production of accurate base map information, including digital orthophotos and planimetrics.
- A comparative understanding of photogrammetry and lidargrammetry is required for acquisition of accurate topographic data, including DEMs, mass points, breaklines, and contours for areas too large to be mapped efficiently using ground survey.

Land development projects, both large and small, require detailed mapping of the current topography, natural and man-made features, and overlay of other relevant geospatial data in a GIS used by engineers in making key decisions. Small mapping projects can be performed by ground surveys, including conventional surveys, GPS surveys, close-range photogrammetric surveys, and terrestrial laser scanning. Large mapping projects are performed by aerial surveys, including aerial photography from film or digital cameras, photogrammetric mapping, and LiDAR mapping of the bare-earth terrain and/or top reflective surfaces (e.g., treetops, rooftops, towers); but they also include ground surveys to map features that are not visible from the air, such as survey monuments, survey corners, boundary lines, culverts, and underground utilities.

Land development routinely requires analyses of land information, flood and erosion hazards, environmental impact, and access to and impact on supporting infrastructure. Land development projects may also require analyses of transportation networks, hydrologic networks, water quality, environmental restoration, and hazardous waste management. The goal of a responsible land development project manager is to eliminate, or minimize, adverse impacts on others. To do this, various forms of mapping support are essential.

The remainder of this appendix focuses on three geospatial disciplines/technologies used in aerial mapping and surveying:

- *Geodesy,* including ellipsoids and horizontal datums, map projections and state plane coordinate systems, heights and vertical datums, scale factors, and major points to understand about geodesy
- *Photogrammetry,* including aerial and terrestrial photography, topographic and planimetric mapping, digital orthophotography, oblique aerial imaging, and major points to understand about photogrammetry
- *LiDAR,* including mapping of the bare-earth topographic surface, top reflective surfaces, lidargrammetry in generation of 3-D breaklines, and major points to understand about LiDAR

GEODESY

"Mapping without geodesy is a felony." This popular sign, displayed on the wall at the National Geodetic Survey, is meant with tongue in cheek; however, mapping without understanding of geodesy can get mapping firms into legal trouble. Misunderstanding the basics of geodesy has cost some firms millions of dollars to correct basic mistakes. Examinations for licensure or certification of photogrammetrists always include basic questions on geodesy.

Geodesy is the science of determining the size and shape of the earth and its gravity field, and the precise location of points on the earth's surface. Generally speaking, *geometric geodesy* is used to define horizontal positions, consistent with the rules of spherical geometry, and *physical geodesy* is used to define elevations, consistent with the rules of gravity. Whenever surveyors level their conventional survey instruments over points on the earth, they are establishing level lines or vertical angular orientations relative to their local direction of gravity—directions that vary with changing mass and density of the earth. Therefore, conventional ground surveys follow the *rules of gravity,* whereas global positioning system (GPS) surveys follow the *rules of geometry.* A surveyor or mapper needs to understand these distinctions in order to make accurate topographic maps used for land development and other applications.

Land development projects sometimes encounter difficulties when engineers or other key personnel do not understand or pay close enough attention to the following:

- Differences between horizontal datums
- Differences between geographic, state plane, and UTM coordinates
- Differences between true north, grid north, and magnetic north
- Differences between vertical datums
- Differences between ellipsoid heights, orthometric heights, and geoid heights
- Differences between measurement units, especially the U.S. survey foot and the international foot

- Formulas and significant figures necessary for accurate coordinate transformations

This section on geodesy is intended to help engineers and planners understand these differences as well as basic geodetic terms that could prevent needless problems from occurring with mapping and land development projects.

Geoid

The force acting on a body at rest on the earth's surface results from the gravitational force and the centrifugal force of the earth's rotation. The total force, the resultant of gravitational force and centrifugal force, yields a gravity vector that has magnitude and direction. The magnitude is called *gravity* (measured in gals), and the direction is called the *plumb line* or *vertical.* There are an infinite number of such equipotential surfaces, both above and below mean sea level, each with different forces of gravity that vary as a function of changes in the earth's mass and density.

Imagine for a moment that the earth is like an onion, with an infinite number of layers, each layer constituting a different equipotential surface on which the force of gravity is equal and the direction of the plumb line is always normal (perpendicular) to each equipotential surface. These layers undulate slightly with local variations in the mass and density of the earth, causing the plumb line to curve as shown at Figure A.1. Ultimately, water flows downhill because of higher gravity at lower elevations.

The *geoid* is that equipotential (level) surface of the earth's gravity field which, on average, coincides with mean sea level in the open, undisturbed ocean. In practical terms, the geoid is the imaginary surface where the oceans would seek mean sea level if allowed to continue into all land areas so as to encircle the earth. The geoid undulates up and down with local variations in the mass and density of the earth. The local direction of gravity is always perpendicular to the geoid.

Ellipsoid

Precise mapping and survey calculations are based on a mathematical surface called an *ellipsoid*—an ellipse of revolution, rotated around the (shorter) polar axis, which approximates the size and shape of the earth. As shown at Figure A.2, these ellipsoids have a semimajor axis a (distance from the ellipsoid's center to the surface along the equatorial plane) and a semiminor axis b (distance from the ellipsoid's center to the poles), where b is shorter than a. From a and b, the flattening f can be calculated [$f = (a - b)/a$].

For centuries, different ellipsoids were used around the world, chosen to best fit the terrain in different geographic areas. Until the 1970s, the United States used the Clarke 1866 ellipsoid that was not earth-centered (the ellipsoid's center did not coincide with the center of the earth). Other countries used different ellipsoids that better fit their local topography (e.g., International, Bessel, and Clarke 1880 ellipsoids used in Europe, Asia, and Africa), but none of those ellipsoids were earth-centered either.

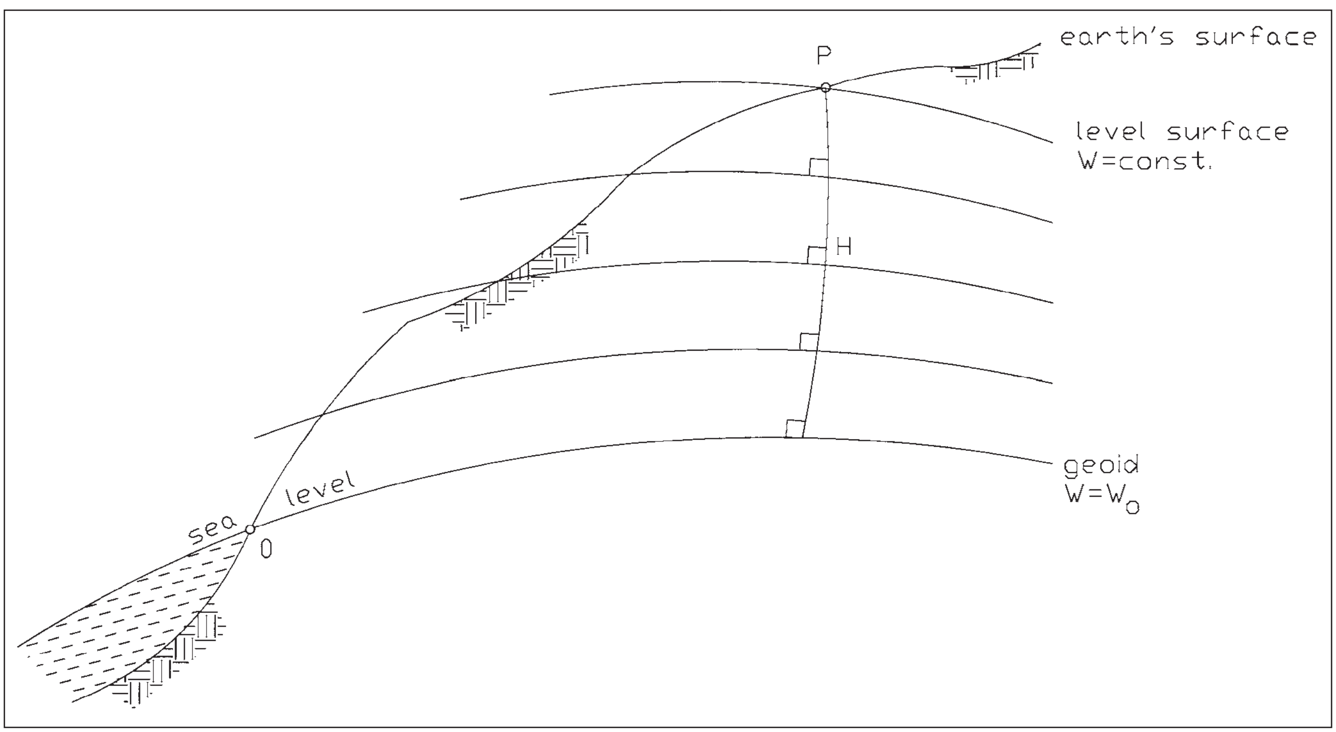

FIGURE A.1 The elevation (orthometric height) of point P above the geoid equals the distance H measured along the plumb line passing through point P. Whereas the plumb line is perpendicular to each equipotential surface, these surfaces are not necessarily parallel to each other, causing the plumb line to curve. Each level has a different gravity potential (W), where W_0 is the potential of the geoid.

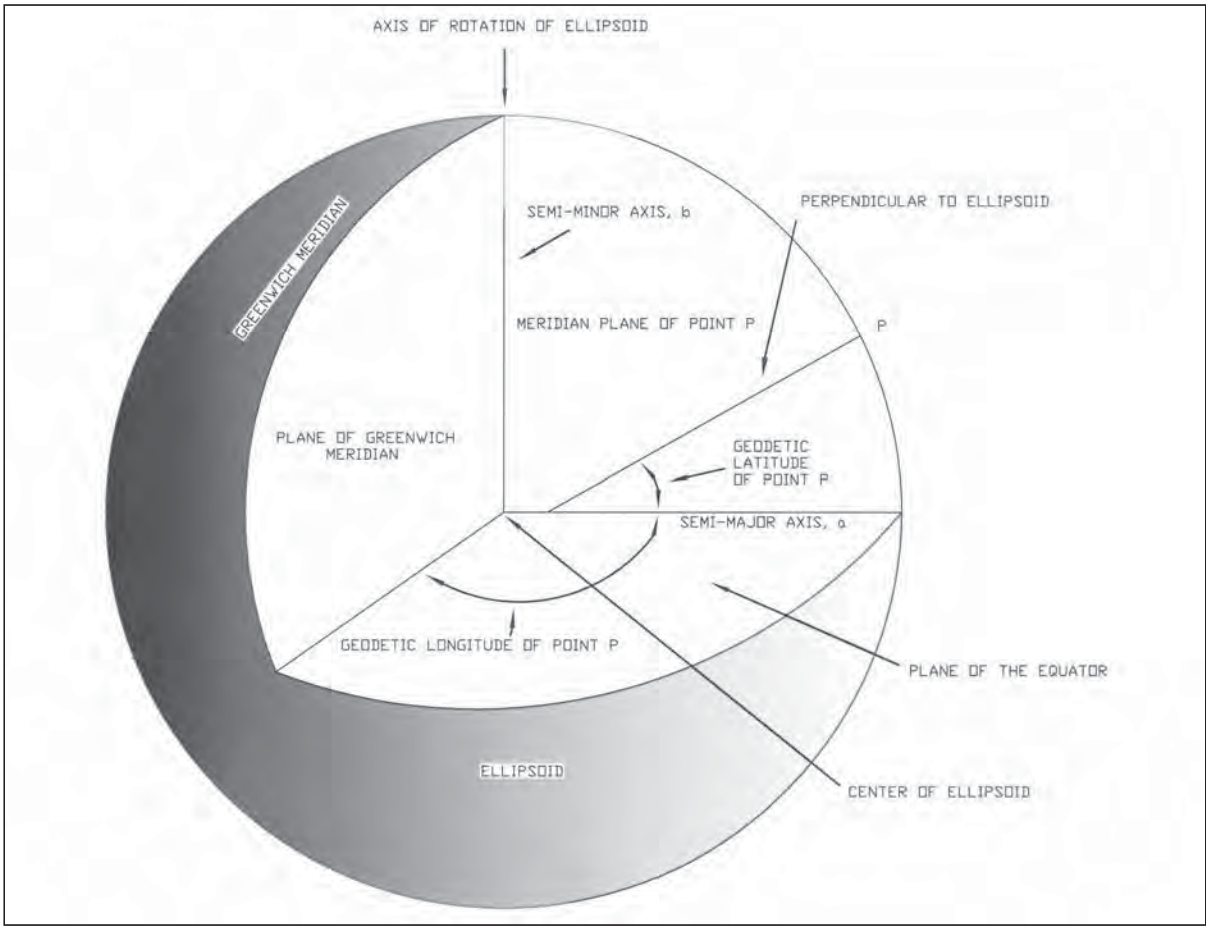

FIGURE A.2 This shows the semimajor axis *a* and semiminor axis *b,* which define an ellipsoid, as well as the geodetic latitude ϕ and geodetic longitude λ of point P. Note that the perpendicular to the ellipsoid does not pass through the center of the ellipsoid; if the earth were spherical instead of ellipsoidal, the perpendicular to the sphere would pass through its center.

With the advent of earth-orbiting satellites in the 1960s and 1970s, the United States was able to develop earth-centered ellipsoids, optimized to fit the entire world and not just individual continents or countries in isolation. One of the first was the World Geodetic System of 1972 (WGS 72), then the Geodetic Reference System of 1980 (GRS 80), and finally the World Geodetic System of 1984 (WGS 84). The defining parameters of the ellipsoids mentioned here are listed in Table A.3. These parameters are embedded in most standard GIS software used in the United States today.

TABLE A.3 Common Ellipsoids

Ellipsoid	Semimajor Axis (a)	Semiminor Axis (b)	Flattening Inverse ($1/f$)
International	6,378,388 meters	6,356,011.9462 meters	285.05419
Bessel 1841	6,377,397.155 meters	6,356,078.9643 meters	299.15283
Clarke 1866	6,378,206.4 meters	6,356,583.8 meters	294.97870
Clarke 1880	6,378,249.145 meters	6,356,514.8696 meters	293.46500
WGS 72	6,378,135 meters	6,356,750.5 meters	298.25972
GRS 80	6,378,137 meters	6,356,752.3141 meters	298.25722
WGS 84	6,378,137 meters	6,356,752.3142 meters	298.25722

The numbers in Table A.3 are rounded for demonstration purposes and often contain many more significant figures than shown here. For example, the Geodetic Reference System 1980 (GRS 80) is the reference ellipsoid currently used for mapping in the United States. Its defining parameters are as follows:

- Semimajor axis = equatorial radius = a = 6,378,137.00000 meters
- Semiminor axis = polar radius = b = 6,356,752.31414 meters
- Flattening = f $(a - b)/a$ = 0.003352810681225
- Inverse flattening = $1/f$ = 298.2572220972

The GRS 80 ellipsoid forms the basis for the current North American Datum of 1983 (NAD 83) and for all practical purposes is identical to the World Geodetic System of 1984 (WGS 84) ellipsoid. The Clarke 1866 ellipsoid formed the basis for the prior North American Datum of 1927 (NAD 27). For comparison purposes, the Clarke 1866 ellipsoid had a semimajor axis a of 6,378,206.4 meters, a semiminor axis b of 6,356,583.8 meters, and inverse flattening $1/f$ of 294.9786982.

Figure A.3 shows the equator, parallels, and meridians used to understand geographic and geodetic coordinates.

Parallels are curved lines of equal latitude north or south of the equator, where the latitude is zero, and *meridians* are curved lines of equal longitude east or west of the prime meridian in Greenwich, England, where the longitude is zero. Figure A.3 clearly shows the *convergence of the meridians,* where the meridians are farthest apart at the equator and converge (get closer together) toward the north and south poles, where they merge.

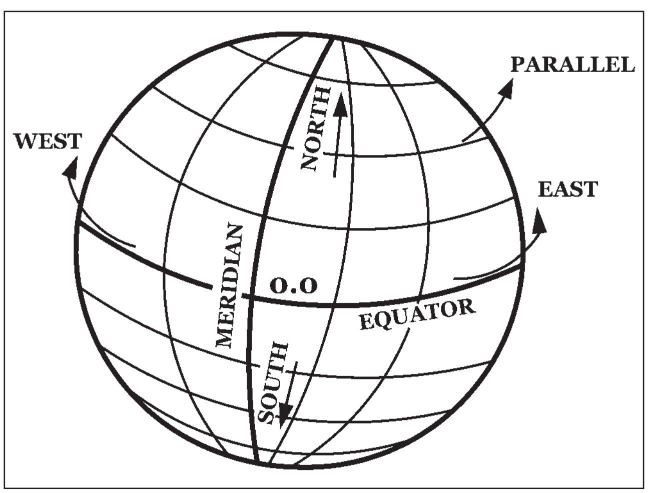

FIGURE A.3 This shows parallels that define latitude north or south of the equator and meridians that define longitude east or west of the prime meridian passing through Greenwich, England. All meridians converge at the north and south poles. Latitude and longitude define the geographic coordinates of a point on the ellipsoid.

Deflection of the Vertical

Conventional surveys typically start by leveling a survey instrument so that the instrument's horizontal line of sight is perpendicular to the local direction of gravity. Whether the surveyor realizes it or not, conventional surveys are subject to what could be called the "rules of gravity." However, unknown to almost everyone, the earth's mass anomalies cause variations in the local direction of gravity.

The equipotential surface known as the geoid is a smooth but undulating surface that always has the direction of gravity perpendicular to it. The *vertical,* a straight line that aligns with the plumb line (direction of gravity) at the earth's surface, is perpendicular to the geoid at that point and usually does not pass through the earth's center of mass. The *normal,* also a straight line, is perpendicular to the ellipsoid and usually does not pass through the center of the ellipsoid. The *deflection of the vertical* is the angle between the normal and the vertical. The *geoid undulation* is the distance, taken along a perpendicular to the ellipsoid, from the ellipsoid to the geoid. Because of undulations in equipotential surfaces, the *plumb line* curves and eventually joins all other plumb lines at the earth's center of mass. The earth's center of mass can now be mathematically defined as the point about which satellites orbit. College courses in physical geodesy, satellite geodesy, and geophysics provide greater details of such theories. Figure A.4 shows how changes in the earth's mass cause the geoid to undulate; it also shows that the ellipsoid's normal and the geoid's vertical are separated by the deflection of the vertical. The deflection of the vertical is never more than 2 arc-minutes anywhere on earth.

Horizontal Datums

A *geodetic datum* is a set of constants specifying the coordinate system used for geodetic control, that is, for calculating the coordinates of points on the earth. A horizontal datum is used to define horizontal coordinates, and a verti-

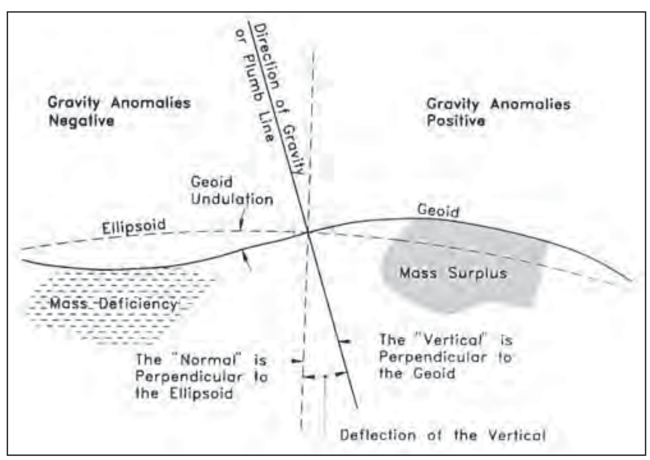

FIGURE A.4 The geoid undulation above and below the ellipsoid and the deflection of the vertical illustrate why the rules of gravity, applicable to the undulating geoid, differ from the rules of geometry, applicable to the mathematically defined ellipsoid.

cal datum is used to define vertical coordinates. Horizontal datums require a reference ellipsoid, an origin, and an angular alignment.

NAD 27, now obsolete, was a horizontal control datum for the United States that was defined by a location and an azimuth on the Clark 1866 ellipsoid, with origin at a survey station known as Meades Ranch (in Kansas) at which the geoid and ellipsoid were forced to coincide, as well as the normals (perpendicular to the geoid, and perpendicular to the ellipsoid). NAD 27 was used as the geodetic datum in the United States for most of the twentieth century. This artificially forced the deflection of the vertical (see Figure A.4) to be zero, and geodesists later realized that this warped the NAD 27 datum relative to earth-centered datums such as NAD 83 and WGS 84, both of which have origins at the center of mass of the earth. It was not until the 1980s that satellite orbits allowed geodesists to define the center of mass of the earth.

NAD 83 is the horizontal control datum now used for the United States, Canada, Mexico, and Central America, based on a geocentric origin and the GRS 80 ellipsoid. NAD is based on the adjustment of 250,000 points, including 600 satellite Doppler stations, which constrain the system to a geocentric origin.

NAD 83 was computed by the geodetic agencies of Canada (federal and provincial) and the National Geodetic Survey in the United States for several reasons. The horizontal control networks had expanded piecemeal since 1933 to cover much more of the countries, and it was very difficult to add new surveys to the network without altering large areas of the previous network. Field observations had added thousands of accurate electronic distance measuring equipment (EDME) baselines, hundreds of additional points with astronomic coordinates and azimuths, and hundreds of Doppler satellite–determined positions. It was also recognized that the Clarke Ellipsoid of 1866 no longer served the needs of a modern geodetic network.

NAD 27 was based on the Clarke 1866 ellipsoid and NAD 83 is based on the GRS 80 ellipsoid. The NAD 27 was computed with a single survey point, Meades Ranch, as the datum point, while the NAD 83 was computed as a geocentric reference system with no datum point. NAD 83 has been officially adopted as the legal horizontal datum for the United States. The computation of the NAD 83 removed significant local distortions from the network that had accumulated over the years, using the original observations, and made the NAD 83 much more compatible with modern survey techniques, including GPS surveys.

Vertical Datums

The National Geodetic Vertical Datum of 1929 (NGVD 29), now obsolete, was originally known as the Sea Level Datum of 1929. It was established for vertical control in the United States by the general adjustment of 1929. Mean sea level was held fixed at the sites of 26 tide gauges—21 in the United States and 5 in Canada. The datum was defined by the observed heights of mean sea level at the 26 tide gauges and by the set of elevations of all benchmarks resulting from the adjustment. A total of 106,724 kilometers of leveling was involved, constituting 246 closed circuits and 25 circuits at sea level.

The North American Vertical Datum of 1988 (NAVD 88) is the current official vertical datum in the United States, established by a minimum-constraint adjustment of the Canadian-Mexican-U.S. leveling observations. It held fixed the height of a single primary tidal benchmark, referenced to the new International Great Lakes Datum of 1985 (IGLD 85) local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. Additional tidal benchmark elevations were not used due to the demonstrated variations in sea surface topography—that is, the fact that mean sea level is not the same equipotential surface at all tidal benchmarks.

NAVD 88 was computed for many of the same reasons as NAD 83. About 625,000 kilometers of leveling had been added to the NGVD since 1929. Thousands of benchmarks had been subsequently destroyed, and many others had been affected by crustal motion, postglacial rebound, and subsidence due to the withdrawal of underground fluids. Distortions amounting to as much as 9 meters had been seen as a result of forcing the new leveling to fit the NGVD 29 height values.

NGS develops and maintains the current NAVD 88. In addition, NGS provides the relationships between past and current geodetic vertical datums. However, another part of NGS's parent organization, the National Ocean Service (NOS), is the Center for Operational Oceanographic Products and Services (CO-OPS). CO-OPS publishes tidal benchmark information and the relationship between NAVD 88 and various water level/tidal datums (Mean Lower Low Water, Mean High Water, Mean Tide Level, etc.). The relationships to NGVD 29 are not published but may be calculated independently from specified tidal benchmark sheet links to the NGS database. Tidal benchmark information, water level/tidal datums, and their relationship to geodetic vertical datums are available at the CO-OPS website: www.co-ops.nos.noaa.gov.

Map Projections

Whereas precise survey calculations are based on a mathematical ellipsoid, survey calculations performed for land development purposes routinely assume the earth is flat, and they utilize a Cartesian coordinate system of 2-D (x-y) or 3-D (x-y-z) coordinates. This section explains how map projections are used to map the nearly spherical earth onto a two-dimensional map sheet, including cylinders and cones that are mathematically cut and laid flat. The next section will explain how State Plane Coordinate Systems are developed from these map projections tailored to best fit individual states within the United States.

To set the record straight from the very beginning, one cannot map a spherical surface onto a flat piece of paper without compromising one or more of the following: angles, distances, or areas. Something has to give! In projecting from a spherical or ellipsoidal surface to a flat surface, the true shape of the features must change. However, map projections can be designed to preserve angles, distances, or areas, within limits, but not all three factors at once:

- Conformal projections (e.g., transverse Mercator and Lambert conformal conic) maintain angular relationships and accurate shapes over small areas; such projections are used for navigation and general mapping.
- Equal area projections (e.g., Peters and Albers equal-area conic) maintain accurate relative sizes; such projections are used for maps that show distributions or other phenomena where showing area accurately is important.
- Equidistant projections (e.g., Equidistant conic or equirectangular) maintain accurate distances from the center of the projection or along given lines; such projections are used for radio and seismic mapping and for navigation.
- Azimuthal projections (e.g., Gnomic and Lambert azimuthal equal-area) maintain accurate directions (and therefore angular relationships) from a given central point; such projections are used for aeronautical charts and other maps where directional relationships are important.

Because conformal projections are used with State Plane Coordinate Systems in the United States, subsequent discussions in this chapter focus primarily on the transverse Mercator and Lambert conformal conic projections, which are conformal projections.

All dimensions surveyed on the earth are changed proportionately when mapped at a reduced scale. Few points, however, are mapped exactly to the specified scale where the *scale factor* is exactly 1.0000000000, where the scale factor = (map distance)/(ground distance × scale). With Universal Transverse Mercator (UTM) coordinates, the scale factor is between 0.99960 and 1.00040. With State Plane coordinates, the scale factor is normally between 0.99990 and 1.00010. The scale factor on any map varies throughout the map and may vary in different directions at any given point.

The overall scale factor (also called the *grid scale factor*) is the product of the *elevation factor* and the *zone scale factor*. The elevation factor accounts for the elevation of the terrain being either above or below the ellipsoidal surface on which map projections are based. As shown in Figure A.5, the elevation factor equals $R/(R + H + N)$, where R = the mean radius of the earth (assume 6,372,000 meters), H = orthometric height or elevation above mean sea level (the geoid), and N = geoid height or separation from the ellipsoid (between −8 and −53 meters in the continental United States, i.e., always a negative number in the preceding equation).

As shown in Figure A.5, where the terrain is above the ellipsoid, the elevation factor will be slightly less than 1.

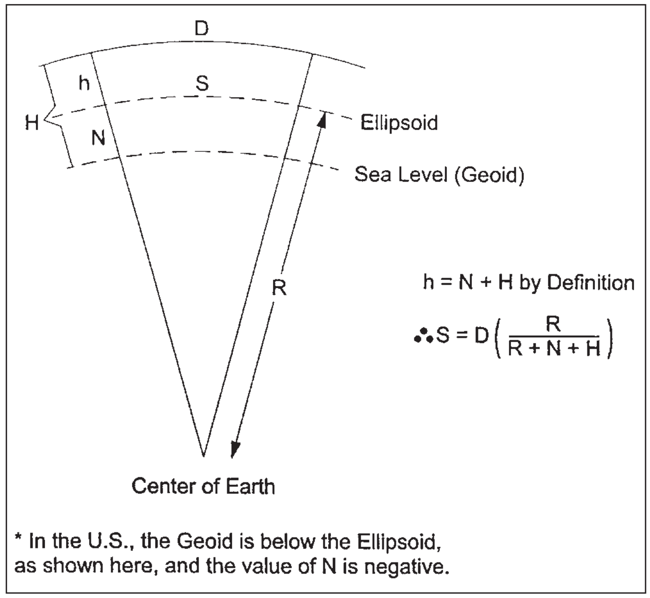

FIGURE A.5 This explains the elevation factor that causes scaling errors as a result of elevations above or below the ellipsoid on which the map projection is based. Features scaled from a map (S) do not exactly match the surveyed ground distances (D) between those features, even after applying the published map scale because of variations in the elevations of mapped features.

Alternatively, if the terrain was near sea level (below the ellipsoid), the elevation factor would be slightly greater than 1.

The zone scale factor accounts for the projection surface being either above or below the ellipsoid on which the map projection is based. The zone scale factor is exactly 1.000000000 only along a line where the projection surface is tangent to the ellipsoid. To better understand this concept, let's see how this works with the three standard projection surfaces: cylinders, cones, and planes.

As shown in Figure A.6 (*top*), imagine the earth to be a *theoretical glass ellipsoid* with all parallels, meridians, and natural and man-made features painted on its surface. Next, imagine an extremely large roll of light-sensitive paper encircling the earth, tangent along the earth's equator, starting and ending back at the Greenwich meridian after circling the earth, forming a huge cylinder with the axis of the cylinder passing through the north and south poles. Then, imagine a light at the center of the (glass) earth, projecting and mapping all painted features onto the paper, which, at full scale, unwrapped and laid flat, would be a huge map approximately 25,000 miles long. Earth features near the equator would be mapped to approximately 1:1 scale, but features north and south of the equator would be distorted, with scale factor errors increasing significantly with increased distance from the equator. The north and south poles would never project to the paper because they would remain inside the cylinder, no matter how long the cylinder is. At some point, users would choose to stop mapping this projection at high northern and southern latitudes because the cylinder would be too long, and distortions would be ridiculous.

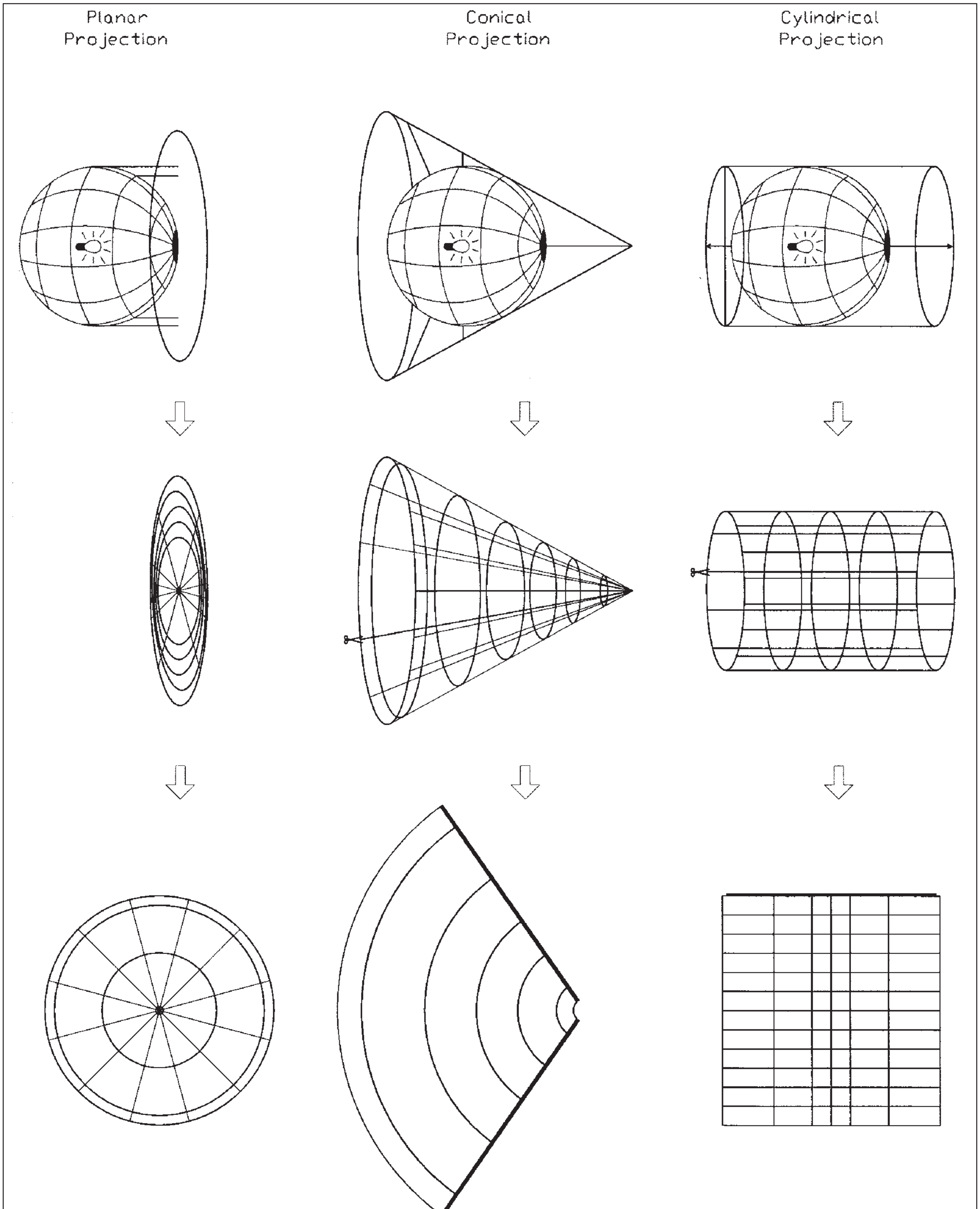

FIGURE A.6 The earth's features, as well as meridians and parallels, can be projected onto a cylinder (*top*), onto a cone (*center*), or onto a plane surface (*bottom*). The cylinder and cone can then be laid flat to make a 2-D map of the 3-D ellipsoid. The lines or points of tangency can be changed to minimize map distortions for areas to be mapped. For example, with the cylindrical projection, instead of being tangent at the equator, the cylinder is commonly turned sideways to be tangent along a selected meridian. With the conical projection, instead of being tangent at the parallel shown, the shape of the cone is commonly changed so as to be tangent to any selected parallel. With the planar projection, instead of being tangent at the north pole, the plane can be moved to be tangent at any selected point on the earth. Wherever the projection surface is tangent to the ellipsoid, the scale factor of the map will be correct (1:1), with scale distortions worsening with increased distance from the lines or points of tangency.

This map would be millions of times too large to fit on anyone's wall, but if this map was photographically or mathematically reduced in scale, it would approximate a map with the Mercator projection commonly used for world maps—maps that predictably show the area of Greenland to be enlarged/distorted compared to Greenland's actual size. The Mercator projection only maintains angular relationships and accurate shapes over small areas near the equator.

Next, imagine this cylinder of paper is turned sideways into a transverse position so that the axis of the cylinder is through the center of the earth and along the equator rather than through the poles, and imagine the cylinder is tangent to the earth along the 0° and 180° meridians. Now, only those features along a narrow north-south strip of land near these meridians would be mapped to scale, and other features would be mapped with scale factor errors that increase with distance east or west of these meridians. All east-west distances and areas would be mapped larger than they really are. This transverse cylinder can be rotated to be tangent along any number of different central meridians, each mapping features to scale along those meridians with scale factor errors increasing for features mapped to the east and west of each central meridian. The transverse Mercator projection only maintains angular relationships and accurate shapes over small areas near to the meridian along the line of tangency.

Next, imagine this transverse cylinder to have a smaller diameter than the earth, as shown in Figure A.7, so there are two *rings of intersection* (A-B and D-E) where the scale is truly 1:1. When the projected surface cuts through the earth, rather than being tangent to it, it is called a *secant projection*. Between these two rings of intersection (e.g., C-M), terrain features map smaller than they really are, and outside these two rings, terrain features map larger than they really are. By controlling the size of this transverse cylinder and limiting the east-west extents of areas mapped, users limit the distortions and scale factor errors to reasonable values. For example, by limiting the zones to 254 kilometers wide for a State Plane Coordinate System, scale factor errors will be between 0.9999 and 1.0001, or one part error in 10,000. Note in Figure A.7 (*top*) that these parallels and meridians are curved lines. When overlaid with an SPCS rectangular grid, *grid north* will differ from *true north* everywhere because of convergence of the meridians, except along the central meridian, which aligns with true north. The cylinder for the UTM projection cuts deeper into the ellipsoid, resulting in scale factor errors between 0.9996 and 1.0004.

National mapping agencies such as the U.S. Geological Survey utilize a UTM projection whereby there are 60 zones, each covering 6 degrees of longitude. Because these zones are much wider than 254 kilometers, a smaller cylinder is used to cut deeper into the earth with a secant projection so as to balance the areas that are larger and smaller than 1.0000. As a result, scale factor errors for the UTM projection are between 0.9996 and 1.0004, or one part error in 2500. The UTM projection is used for military maps that are universal, are used by U.S. forces and allies, and are not tailored to dimensions of individual countries. Whereas the UTM projection and UTM coordinates have appeal internationally and for large national mapping programs, their errors are considered to be too large for use in land development and construction projects in the United States where State Plane coordinates are used because of their greater accuracy and conformance to measurements surveyed on the ground.

Returning to Figure A.6 (*center*), imagine this same theoretical glass ellipsoid is draped with a huge cone of paper, tangent to the earth at the fortieth parallel (40 degrees north latitude). Using the light at the center of the earth to project features onto the cone, all features close to the fortieth parallel would be mapped close to true scale, but feature distortion would increase with greater distance north or south from the fortieth parallel. Next, imagine the cone's apex rising upward so that the cone is steeper and parallel to the ellipsoid at the thirtieth parallel. Now all features close to the thirtieth parallel would be mapped close to true scale, but feature distortion would increase with greater distance north or south from the thirtieth parallel. By raising or lowering the cone's apex, the cone can be made to be tangent to any desired parallel. For this reason, conic projections are preferred for mapping areas that are longer in the east-west direction where the land mass is closer to a single parallel, such as the state of Tennessee. The cone can also be unwrapped and laid flat so it forms a plane surface.

Next, imagine a secant cone cutting through the earth, as shown in Figure A.8, so that there are two *standard parallels* (A-B and C-D) where the scale is truly 1:1. This is a Lambert conformal conic projection used to establish the SPCS for many states in the United States. Between the standard parallels, terrain features are mapped smaller than they really are, and outside these standard parallels, terrain features are mapped larger than they really are. On a state-by-state basis, standard parallels can be moved north or south by changing the cone's apex and shape, making the cone steeper or shallower, and limiting the scale factor errors.

Returning again to Figure A.6 (*bottom*), it shows a planar projection where the theoretical glass ellipsoid is tangent at the north pole, the only point where the scale is truly 1:1; at all other locations, features would map larger than they really are. To limit such distortions, planar projections can also be secant, such as the polar stereographic projection widely used for mapping areas in the vicinity of the north and south poles. Planar projections do not need to be tangent or secant at the poles only; they could be tangent or secant anywhere on earth, but then for relatively small areas only. The Washington Dulles International Airport Coordinate System, described later, is one such use of a planar projection.

State Plane Coordinate Systems

Sometime around 1930, an engineer from the North Carolina state government approached the Coast and Geodetic Survey (C&GS, now NGS) and inquired about the possibil-

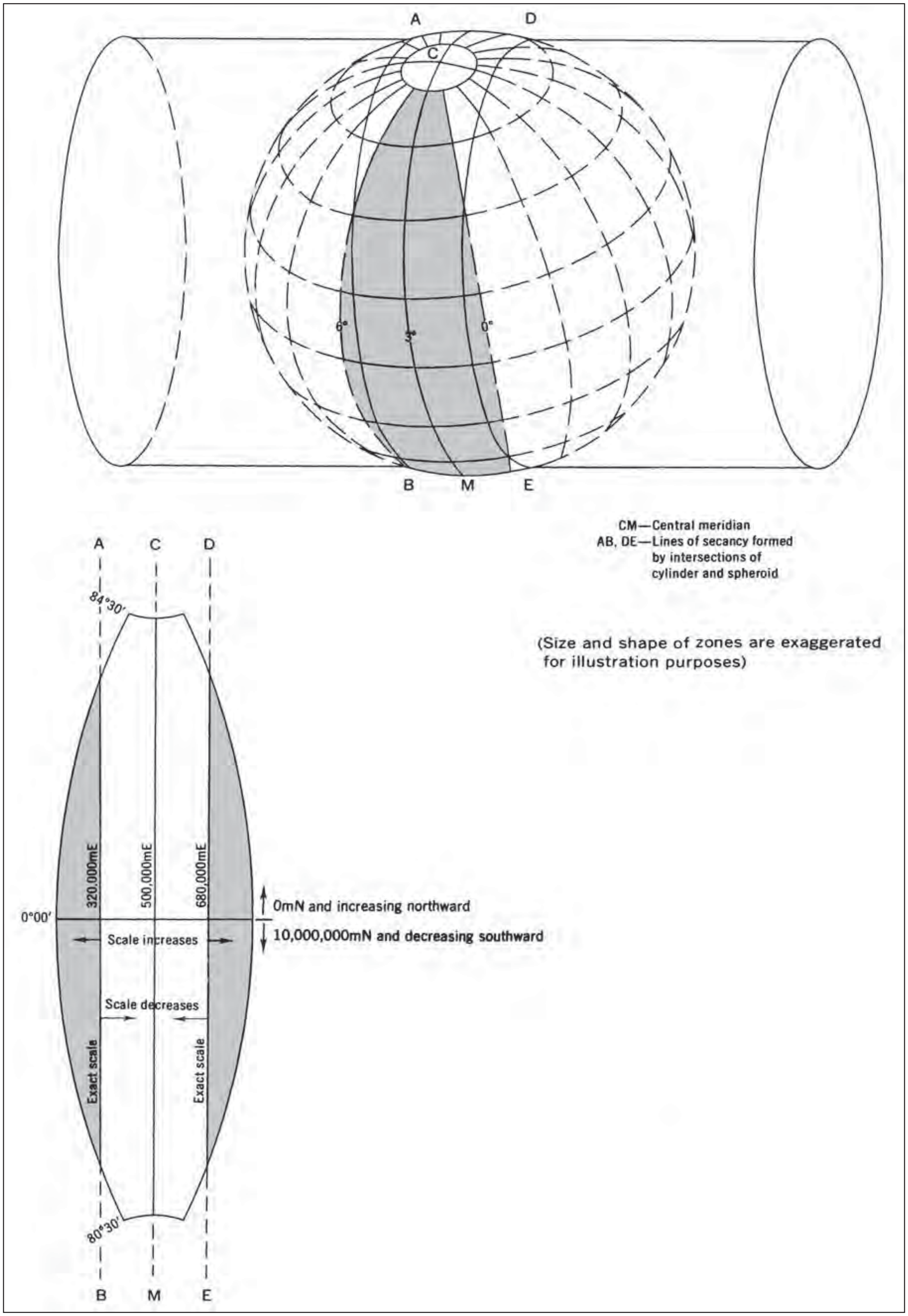

FIGURE A.7 Cylinder used for a transverse Mercator projection with two rings of intersection shown as A-B and D-E. Between these rings the scale is less than 1:1; outside these rings the scale is larger than 1:1. Meridians are mapped as slightly curved lines, except for the chosen central meridian, which is a straight line and where true north aligns with grid north. Parallels are mapped as slightly curved lines also, except at the equator.

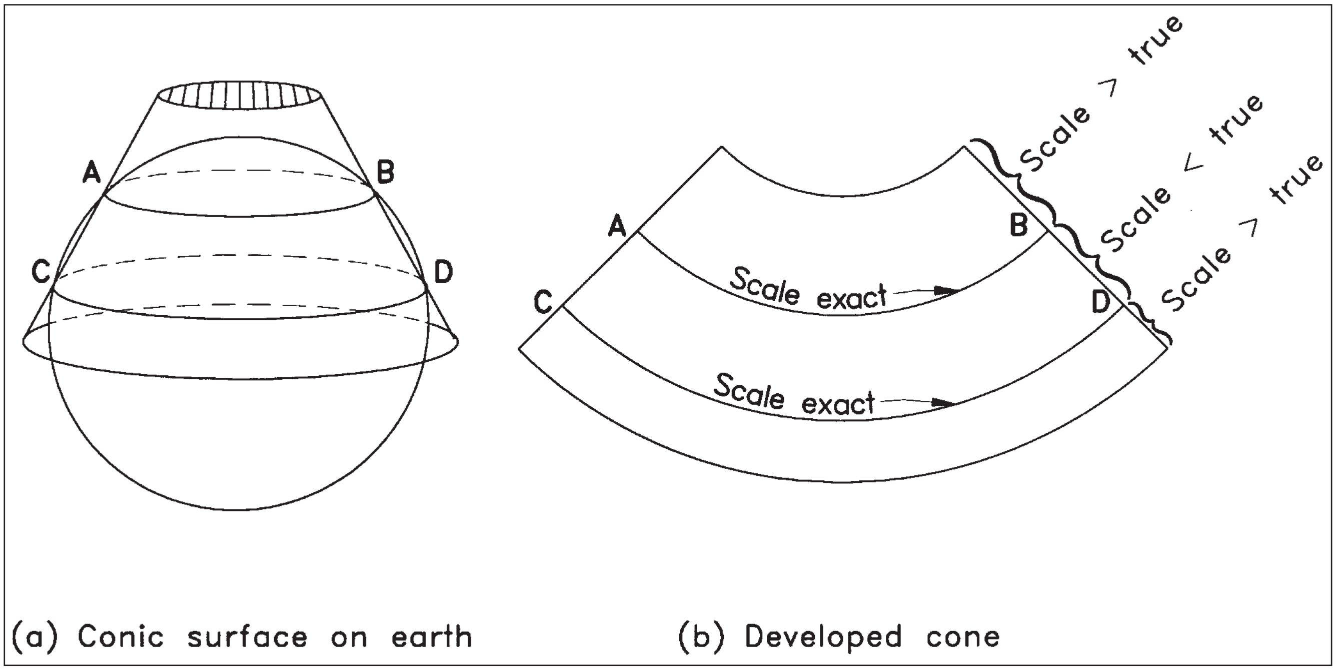

FIGURE A.8 Secant cone, cutting through the ellipsoid along two chosen standard parallels (A-B and C-D) used for a Lambert conformal conic projection. Between these two standard parallels the scale is less than 1:1; outside these standard parallels the scale is larger than 1:1. Meridians are mapped as nonparallel straight lines that will divert from grid north except along the central meridian chosen for the map projection; grid north aligns with true north only along the chosen central meridian. Parallels are mapped as slightly curved lines (segments of circular lines) everywhere.

ity of using simple techniques to survey and map the entire state with rectangular grid coordinates. The engineer wanted to ignore the curvature of the earth and assume the earth's surface to be a flat plane; such simple techniques are called *plane surveying techniques.* The C&GS explained that it's impossible to flatten the curved surface of the earth into a plane without distorting the surface in one way or another, but this inquiry led to a cooperative venture between the C&GS and the North Carolina state government to build a North Carolina spatial coordinate system with *minimal* distortion so that the scale factor was as close as possible to 1:1. In 1933 this cooperative venture produced the North Carolina Coordinate System. In less than 12 months, the North Carolina system had been copied for all of the remaining states, and the SPCS was born. Today the SPCS covers all 50 states.

State Plane Coordinate Systems were developed to keep scale factor errors smaller than one part in 10,000. With variations tailored for each state, Transverse Mercator projections are used as the basis for State Plane coordinates for *tall states* that are longer in the north-south direction, and Lambert conformal conic projections are used as the basis for State Plane coordinates for *wide states* that are longer in the east-west direction. To limit distortions to within this range, the C&GS (now NGS) limited the north-south dimension of each Lambert conformal conic zone and the east-west dimension of each transverse Mercator zone to 254 kilometers. If tall states are wider than 254 kilometers, or if wide states are taller than 254 kilometers, they would normally have two or more SPCS zones. Regardless of projection, each SPCS zone requires a central meridian with origin (ϕ_0, λ_0) and *false easting* (E_0) and *false northing* (N_0) coordinates for the origin so that all easting and northing coordinates are positive numbers within a normal range of values. Regardless of whether the transverse Mercator or Lambert conformal conic projection is used, grid north is different from true north at all locations except for points along the central meridian of each SPCS zone. Only along the central meridian of these two projections does true north align with grid north.

State Plane Coordinate Systems are not projections, but they rely on projections to minimize distortions on SPCS grids. Let's look at two examples.

Indiana, for example, is a *tall state* that is longer in the north-south direction, and its east-west extent is between 254 and 508 kilometers, requiring two transverse Mercator zones (east zone 1301 and west zone 1302):

- Indiana's east zone has its central meridian at 85.66666666666667 degrees west longitude where its scale factor is 0.9999666666666667. The latitude of the origin is 37.5 degrees north latitude, and its longitude is the same as that of the central meridian for the east zone. The false easting for the east zone's origin is 328083.3333333333 U.S. survey feet, and the false northing for the origin is 820208.3333333333 U.S. survey feet.
- Indiana's west zone has its central meridian at 87.08333333333333 degrees west longitude where its scale factor is 0.9999666666666667. The latitude of the origin is 37.5 degrees north latitude, and its longitude is

the same as that of the central meridian for the west zone. The false easting for the west zone's origin is 2952750.0000000000 U.S. survey feet, and the false northing for the origin is 820208.3333333333 U.S. survey feet.

Similarly, Virginia is a *wide state* that is longer in the east-west direction, and its north-south extent is between 254 and 508 kilometers, requiring two Lambert conformal conic zones (north zone 4501 and south zone 4502).

- Virginia's north zone has its central meridian at 78.5 degrees west longitude. The two standard parallels (where the scale factor is exactly 1) are: 38.03333333333333 degrees and 39.2 degrees north latitude. The latitude of the origin is 37.6666666666667 degrees north latitude and its longitude is the same as that of the central meridian for the north zone. The false easting for the north zone's origin is 11482916.66666666 U.S. survey feet, and the false northing for the origin is 6561666.666666666 U.S. survey feet.
- Virginia's south zone has its central meridian at 78.5 degrees west longitude. The two standard parallels (where the scale factor is exactly 1) are at 36.76666666666667 degrees and 37.96666666666667 degrees north latitude. The latitude of the origin is 36.33333333333334 degrees north latitude and its longitude is the same as that of the central meridian for the south zone. The false easting for the south zone's origin is 11482916.66666666 U.S. survey feet, and the false northing for the origin is 3280833.333333333 U.S. survey feet.

Generally, the boundaries between state plane zones within a state follow county boundary lines so that entire counties are within a single SPCS zone. This makes the north-south boundary between east and west zones and the east-west boundary between north and south zones an irregular line, as shown in Figure A.9. The only exception to this county boundary rule is in Alaska, where counties do not exist. Alaska also has one SPCS zone that uses neither the Lambert conformal conic nor the transverse Mercator projections, instead using an oblique Mercator projection for a portion of the coast that runs from the southeast to the northwest. This is the only exception to the two standard map projections used nationwide with State Plane Coordinate Systems.

Florida uses both transverse Mercator and Lambert conformal conic projections for its SPCS. Florida's East zone is a transverse Mercator zone that covers eastern Florida, including its Atlantic coast. Florida's West zone is a transverse Mercator zone that covers southwestern Florida, including its western coast on the Gulf Coast up through Levy County. Florida's North zone is a Lambert conformal conic zone that

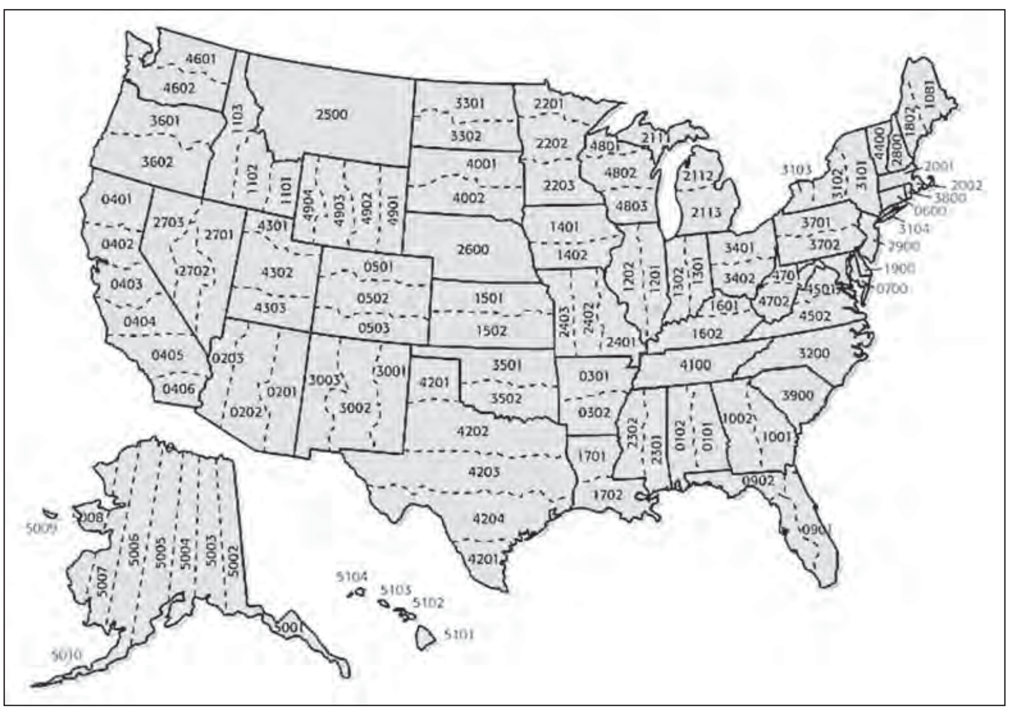

Figure A.9 With few exceptions (e.g., Montana and Nebraska), most states have adopted a State Plane Coordinate System to keep scale factors between 0.99990 and 1.00010 so that scaling errors will be 1:10,000 or less. Generally speaking, states longer in the north-south direction utilize one or more transverse Mercator zones, whereas states longer in the east-west direction utilize one or more Lambert conformal conic zones. Zone boundaries normally curve to coincide with county boundaries in order to keep entire counties within a single zone.

covers northern Florida, including the southern coast on the Gulf along the Florida panhandle.

There are a total of approximately 120 SPCS zones throughout the United States, and the total varies, as some states decide to adopt a single SPCS zone rather than multiple zones. Montana and Nebraska, for example, chose to retain a single SPCS zone even though they are taller than 254 kilometers; such states accept scale factor errors greater than 1 in 10,000.

It is important for planners to understand two additional facts about State Plane coordinates:

- Some states are metric, with State Plane coordinates in meters, whereas other states use English measurements in feet.
- Most counties use the U.S. survey foot as the unit of measurement while other counties in the same state use the International standard foot. The difference is approximately 1 part in 500,000 and is negligible in some cases. Still it is important for everyone to agree on the unit of measure for each project.

When converting between metric and English units in an SPCS, it is important to use all decimal places in the conversion factor. The author is aware of one project that cost an engineering firm over $1 million to correct errors in converting from meters to feet because the conversion factor 3.28 was used instead of 3.2808333, causing errors in excess of 10 feet in coordinates because of this oversight.

In some cases, users cannot accept errors amounting to 1 part in 10,000 as per the SPCS. One such case involved the Washington Dulles International Airport Coordinate System, designed by the author's company (Dewberry), in which a central meridian was supposed to align with the centerline of the main north-south runway, and for which the scale factor errors had to be less than 1 part in 10,000,000, that is, scale factor errors between 0.9999999 and 1.0000001 anywhere on the airport property. During the conduct of this contract, and after extensive surveys, the author demonstrated to the client that the runway was not constructed true north and south, as initially believed (and as preferred by pilots), but was aligned approximately to grid north on the Virginia SPCS. Whereas a survey monument at the north end of the runway was only 4 inches off from grid north (relative to a monument at the southern end of the runway on the Virginia SPCS grid), it is more than 130 feet off from true north; that is, it is misaligned from true north by approximately 39 arc-seconds (nearly ⅔ of 1 degree). In developing the Dulles Airport Coordinate System, the author had to abandon plans to use a grid based on the transverse Mercator projection for which the central meridian must be true north—instead resorting to a secant, planar projection with origin at the south end of the main runway, and making the Airport Coordinate System much more complicated than initially planned. The client was surprised to learn of this significant difference. The author has never learned whether this runway alignment was intentional or unintentional when initially surveyed and constructed, but the fact remains that *it is entirely possible for an airport runway to be misaligned by the difference in azimuth between grid north and true north if the design engineers and surveyors do not recognize the difference between these terms.* With visual flight rules, pilots can compensate for such misalignments, but the day may come when automated landing procedures could bring a plane in for landing on the wrong bearing.

Elevations and Heights

Figure A.10 shows the physical terrain, with elevations above the *ellipsoid* and elevations above the *geoid.* These elevations are technically called *heights.* Elevations above the ellipsoid, called *ellipsoid heights* (h), follow the rules of geometry (as do GPS surveys), whereas elevations above the geoid, called *orthometric heights* (H), follow the rules of gravity (as do conventional surveys with differential levels, theodolites, and total stations). Elevation data can be presented as both ellipsoid heights and orthometric heights, but the popular term *elevation* normally refers to the orthometric height of a point, that is, its height above the geoid as measured along the plumb line between the geoid and a point on the earth's surface, taken positive upward from the geoid.

The *orthometric heights* (H_A and H_B) of points A or B above the geoid are measured along the *plumb lines* (direction of gravity) at those points; the *ellipsoid heights* (h_A and h_B) of points A or B are measured along the ellipsoid *normal* (perpendicular to the ellipsoid); the *geoid heights* or *undulations* (N_A and N_B) are the differences between the ellipsoid heights and the orthometric heights at A and B; and the *deflections of the vertical* (see Figure A.4) are the angular differences between the ellipsoid normal and the plumb line at A and B.

Ellipsoid heights from GPS surveys are converted to traditional orthometric heights by applying the geoid height, using the latest geoid model available from the NGS. This is

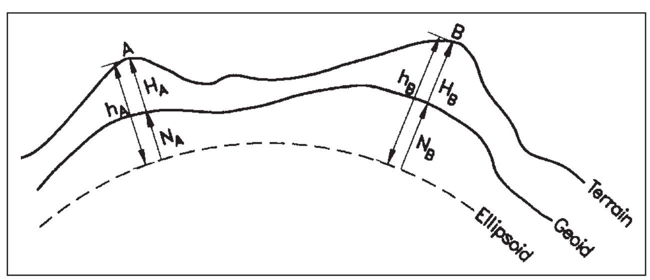

FIGURE A.10 This shows the three reference surfaces used in mapping (physical terrain, geoid, and ellipsoid) and the primary parameters used for mapping elevations: orthometric height H above the geoid, ellipsoid height h above the ellipsoid, and geoid height N or geoid undulation between the ellipsoid and geoid. For application in the internationally used geodetic equation $H = h - N$, N is always a negative number in the continental United States. Whereas this figure shows the geoid above the ellipsoid as in much of the world, in the United States, the geoid is below the ellipsoid, causing N to be a negative number.

currently Geoid03. The standard geodetic conversion formula is: $H = h - N$.

As indicated, the *geoid* is an equipotential surface (equal force of gravity throughout) equivalent to that at mean sea level. There are other equipotential surfaces above and below the geoid that have lesser and greater forces of gravity than along the geoid. The higher above the earth's surface one theoretically goes, the lesser the force of gravity. The closer to the center of the earth one theoretically goes, the more confusing it becomes because there are masses on all sides pulling in every conceivable direction. The earth's center of mass is the balancing point about which satellites orbit.

Elevations (orthometric heights) are derived mathematically but follow gravimetric principles. Geodesists sometimes describe the geoid as a smooth but undulating surface that defines where mean sea level would go if the land mass theoretically got out of the way, perhaps forming narrow trenches for the water to pass inland while retaining the mass excesses and deficiencies that cause the geoid to undulate. Even the ocean surface undulates because of nonhomogeneous variations in the mass of the earth beneath the ocean waters.

The first and second editions of *Digital Elevation Model Technologies and Applications: The DEM Users Manual,* edited by the author and published by the ASPRS, includes an entire chapter on vertical datums, including the National Geodetic Vertical Datum of 1929 (NGVD 29), the North American Vertical Datum of 1988 (NAVD 88), the International Great Lakes Datum of 1985 (IGLD 85), and numerous tidal datums including Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Sea Level (MSL), Mean Low Water (MLW), Mean Lower Low Water (MLLW), and other tidal values including Mean Tide Level (MTL), Diurnal Tide Level (DTL), Mean Range (Mn), Diurnal High Water Inequality (DHQ), Diurnal Low Water Inequality (DLQ), and Great Diurnal Range (Gt). Rather than explaining in detail the differences, the following major points are summarized:

- There are a large number of vertical datums used in the United States.
- There can be large differences between these various datums—as much as tens of meters in elevations.
- Users must know which vertical datum their products are referenced to.
- Users should not combine datasets that are referenced to different vertical datums.
- Published local mean sea level heights (LMSL) and published national vertical heights (NAVD 88) are not the same.
- New technology heights may not be compatible with old published heights.
- Areas subject to subsidence are particularly suspect.
- Users should reference their products to the latest National Vertical Datum, NAVD 88, because of traceability and the likelihood of being able to transfer from one datum to another.

Major Points to Remember about Geodesy

- The reference ellipsoid most commonly used in the United States is the Geodetic Reference System of 1980 (GRS 80).
- The horizontal datum most commonly used in the United States is the North American Datum of 1983 (NAD 83); NAD 83 coordinates are not the same as NAD 27 coordinates. Similarly, the official vertical datum in the United States is the North American Vertical Datum of 1988 (NAVD 88). Users must know what datums their products are referenced to and not combine datasets that are referenced to different datums.
- Map projections always have scale factor errors between distances measured and scaled on maps and distances measured on the ground. Most State Plane Coordinate Systems have scale factor errors limited to 1 part in 10,000, but Montana and Nebraska are exceptions, with larger scale factor errors.
- State Plane Coordinate Systems utilize rectangular grids of eastings and northings; grid north is almost always different from true north and could cause the misalignment of features such as airport runways if not taken into account.
- Some State Plane Coordinate Systems are based on metric units, whereas others are based on English units. Furthermore, some counties use the U.S. survey foot, while other counties in the same state use the International standard foot with slightly different dimensions.
- Measurement units and full conversion factors must be clearly defined.
- Ellipsoid heights from GPS surveys are not the same as orthometric heights from traditional land surveys.
- Areas subject to subsidence require special considerations for which the National Geodetic Survey (NGS) state advisor should be consulted for advice.

PHOTOGRAMMETRY

Photogrammetric Applications

Photogrammetry is an art, a science, and a technology. Aerial photogrammetry uses stereo aerial photographs or stereo digital images to create planimetric and/or topographic maps of features visible on the imagery and to determine the relative location of points, lines, and areas for determination of distances, angles, areas, volumes, elevations, sizes, and shapes of mapped features. Photo interpretation of such imagery deals with recognizing and identifying objects on the imagery and judging their significance through careful and systematic analyses.

Stereo photographs or stereo images are those taken of the same area on the ground but viewed from two perspectives. Aerial stereo photographs are commonly flown with each image having a 60 percent overlap with the preceding and subsequent images; this enables 60 percent of each photograph to overlap the same area shown on the preceding photograph, 60 percent of each photograph to overlap the same area shown on the subsequent photograph, and 10 percent of each photograph to appear on three successive photographs. With stereoscopic viewing, much greater depth perception can be obtained. Stereoscopic viewing enables the formation of a three-dimensional stereomodel for viewing a pair of overlapping photographs, making accurate 3-D measurements and mapping elevations in addition to planimetric detail.

Terrestrial photogrammetry follows the same general principles as aerial photogrammetry except that special metric cameras are mounted on tripods and the line of sight is generally horizontal rather than vertical, but still photographing the same area from two different perspectives.

A large percentage of photogrammetric applications have traditionally pertained to topographic mapping, at various scales, for planning and design of transportation features (highways, railroads, rapid transit systems, airfields, bridges, culverts), pipelines, aqueducts, transmission lines, flood control structures, river and harbor improvements, urban renewal projects, shopping malls, and housing areas, for example. Two newer photogrammetric products, *digital orthophotos* and *digital elevation models,* are now often used in combination to replace traditional topographic maps. An orthophoto is an aerial photograph that has distortions removed, has a uniform scale throughout, and has the metric properties of a planimetric map; however, unlike planimetric maps that show features by using lines and symbols, orthophotos show the actual images of features, making them easier to interpret. A digital elevation model (DEM) is an array of points with *x-y-z* coordinates. DEMs model the 3-D topography or shape of the terrain from which contours, cross sections, and profiles can be computed. Orthophotos and DEMs are widely used in all fields where maps are used, but because they are in digital form, they are ideal for use in geographic information systems (GISs).

Photogrammetry is often used to supplement land surveys. Although aerial photographs don't show boundary lines, aerial photos and/or orthophotos can be used as rough base maps for relocating existing property boundaries. If the point of beginning or any corners can be located with respect to ground features that can be identified on aerial photos, an entire parcel can be plotted on the orthophoto from the property description. All corners can then be located on the photo in relation to identifiable ground features, which, when located in the field, greatly assist in finding the actual property corners. Aerial photos can also be used in planning ground surveys. Through stereoscopic viewing, areas can be studied in 3-D; access routes to remote areas can be identified, and surveying lines of least resistance through difficult terrain or forests can be found. Photogrammetrists map areas without actually setting foot on the ground, avoiding the need to gain access to private land for surveys, avoiding surveys in wetlands and terrain where ground mobility is difficult, and avoiding surveys along highways where land surveys are either unsafe to surveyors or slow the flow of traffic while surveys are in progress.

Photogrammetry is especially important for highway planning and design. Aerial photographs are used in preliminary planning for selection of corridors for new routes. Large-scale topographic maps, contours, and/or DEMs are used in final design. Cross sections are used to compute cut and fill for earthwork quantities in contracts. Plan profile sheets of highway plans are prepared from aerial photos and/or orthophotos. Partial payments and final payments are often calculated from photogrammetric measurements made on photographs acquired during various stages of construction. Information collected from photogrammetry is normally compiled in computer-aided design and drafting (CADD) formats such as AutoCAD .dwg or MicroStation .dgn formats commonly used for highway design, reducing costs and enabling better overall highway design and construction. The same is true for other land development projects such as construction of new housing areas and commercial and industrial areas. Other photogrammetric applications include the mapping of building footprints and the preparation of tax maps, soil maps, forest maps, geological maps, planning and zoning maps, and land use/land cover maps. Photogrammetry is used in the fields of astronomy, architecture, archaeology, geomorphology, oceanography, hydrology and water resources, conservation, ecology, and mineralogy, enabling the harsh outdoor environment to be surveyed, mapped, and analyzed in the comforts of an office.

Photogrammetric Equipment

Although rapidly being replaced by digital cameras for large mapping projects, the traditional aerial film camera is still the most economical for mapping of typical land development projects. Except for oblique imagery (discussed later), used for special applications, most aerial photos are vertical, meaning the cameras are intended to point straight down. Photographs are rarely truly vertical because of unavoidable roll and pitch of the aircraft in flight, but near-vertical photographs are still the goal.

Cameras with 6-inch focal length are the most common for general-purpose applications, balancing the preference for long focal lengths to maximize horizontal accuracy and short focal lengths to maximize vertical accuracy of topographic maps. Figure A.11 shows how rays of light from points A, B, C, and D on the ground are imaged through the lens focal point to be recorded as points a′, b′, c′, and d′ on the film *negative*. *Positives* of those same *negatives* display those points at a, b, c, and d on a film positive or contact print.

Whether acquired from traditional aerial film cameras or modern digital cameras, aerial imagery records perspective

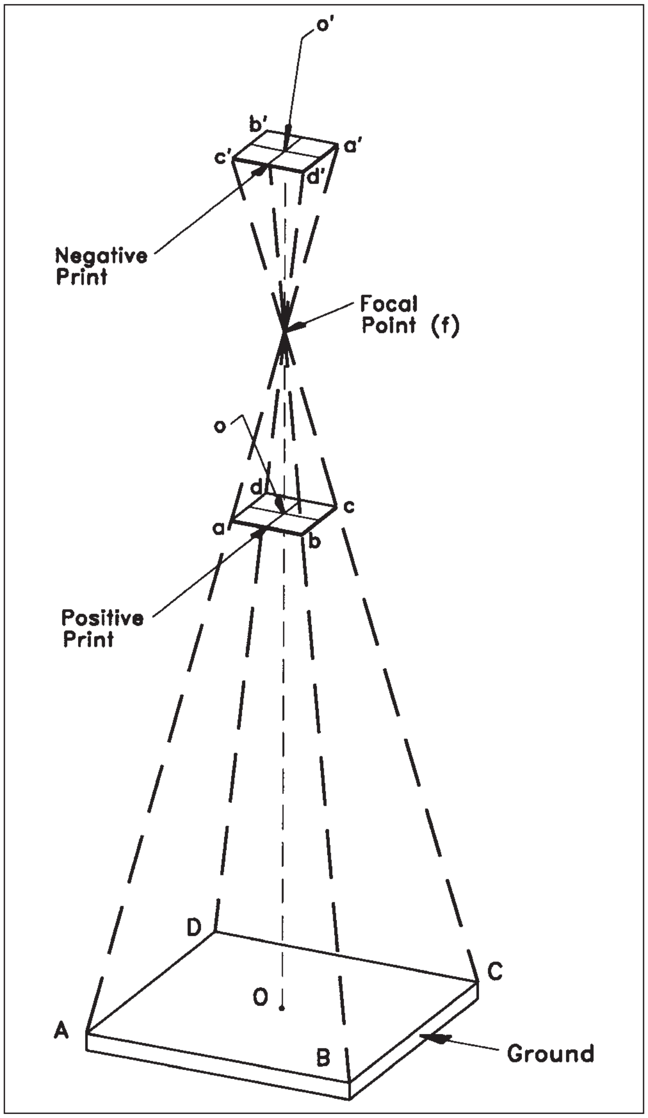

FIGURE A.11 Vertical aerial photo geometry.

views of the terrain. Features that are taller or closer to the camera appear larger than features that are farther away. Thus, aerial imagery inherently has *relief displacement* that causes the images of elevated features to be displaced outward from the center of each photo or image. Furthermore, aerial photographs are rarely truly vertical (i.e., looking straight down at the ground); there is normally some degree of roll, pitch, and yaw of the aircraft that causes photographs to be slightly oblique. Thus, aerial photographs also inherently have *tilt displacement* that causes some features to be tilted outward while other features are tilted inward relative to the center of an aerial photograph.

The objective of traditional photogrammetric mapping is to remove all relief displacement and tilt displacement in order to map the terrain with an orthographic projection as though every feature on the ground were viewed looking straight down from infinity. Figure A.12 shows how aerial photography is planned to achieve the desired scale of photography and the desired forward overlap of 60 percent or more between consecutive photographs. With *stereo* coverage (same terrain photographed from two different perspectives), stereo photogrammetric techniques can be used to map features in three dimensions. Figure A.13 shows how 3-D coordinates of points on the ground are mapped from 2-D coordinates of those points as imaged on stereo photographs. Automated image correlation is commonly used to map either the digital surface model (DSM) or the digital terrain model (DTM). The DTM requires additional editing to remove elevations of vegetation and man-made features above the bare-earth terrain. Then the DTM is used as the terrain model over which a single aerial photograph can be draped in order to produce a digital orthophoto of the terrain. The generic digital elevation model (DEM) is generally synonymous with the DTM, although a DEM usually has regularly spaced elevation points, whereas a DTM has irregularly spaced elevation mass points and breaklines.

There are three distinct generations of photogrammetric equipment that might be used for planimetric and/or topographic mapping for land development projects.

Analog Plotters. Used with hard-copy aerial photos only, analog plotters are optical/mechanical photogrammetric instruments that physically replicate (at reduced scale) the spatial geometry that existed when the aerial photographs were taken. Analog plotters use different techniques to enable the photogrammetric map compiler to see the stereo images in 3-D, determine the elevation of points on the ground, and plot contour lines. Although generally considered to be obsolete in the United States, analog plotters are still used by some photogrammetric companies for small mapping projects such as those for land development projects. Because of limited capabilities to correct for nonlinear distortions, analog plotters are the least accurate and the least efficient.

Analytical Plotters. Also used with hard-copy aerial photos, analytical plotters are computerized photogrammetric instruments that mathematically replicate the spatial geometry that existed when the aerial photographs were taken. Special optics enable the photogrammetric map compiler to see simultaneously the stereo images in 3-D and place a floating dot on the ground to determine the elevation of any point seen in stereo. When set for a specific elevation, the floating dot can be moved along the ground to trace a contour line at uniform elevation. Analytical plotters are very accurate and excellent for land development mapping projects.

Soft-Copy Workstations. Used with digital imagery only (including scanned film), soft-copy photogrammetric workstations mathematically replicate the spatial geometry that existed when the aerial imagery was acquired. Polarized images or other sophisticated techniques enable the photogrammetric map compiler to see simultaneously the stereo images in 3-D on a computer screen and determine the elevation of any point seen in stereo. Looking at the computer screen with polarized glasses (or alternative procedures), the

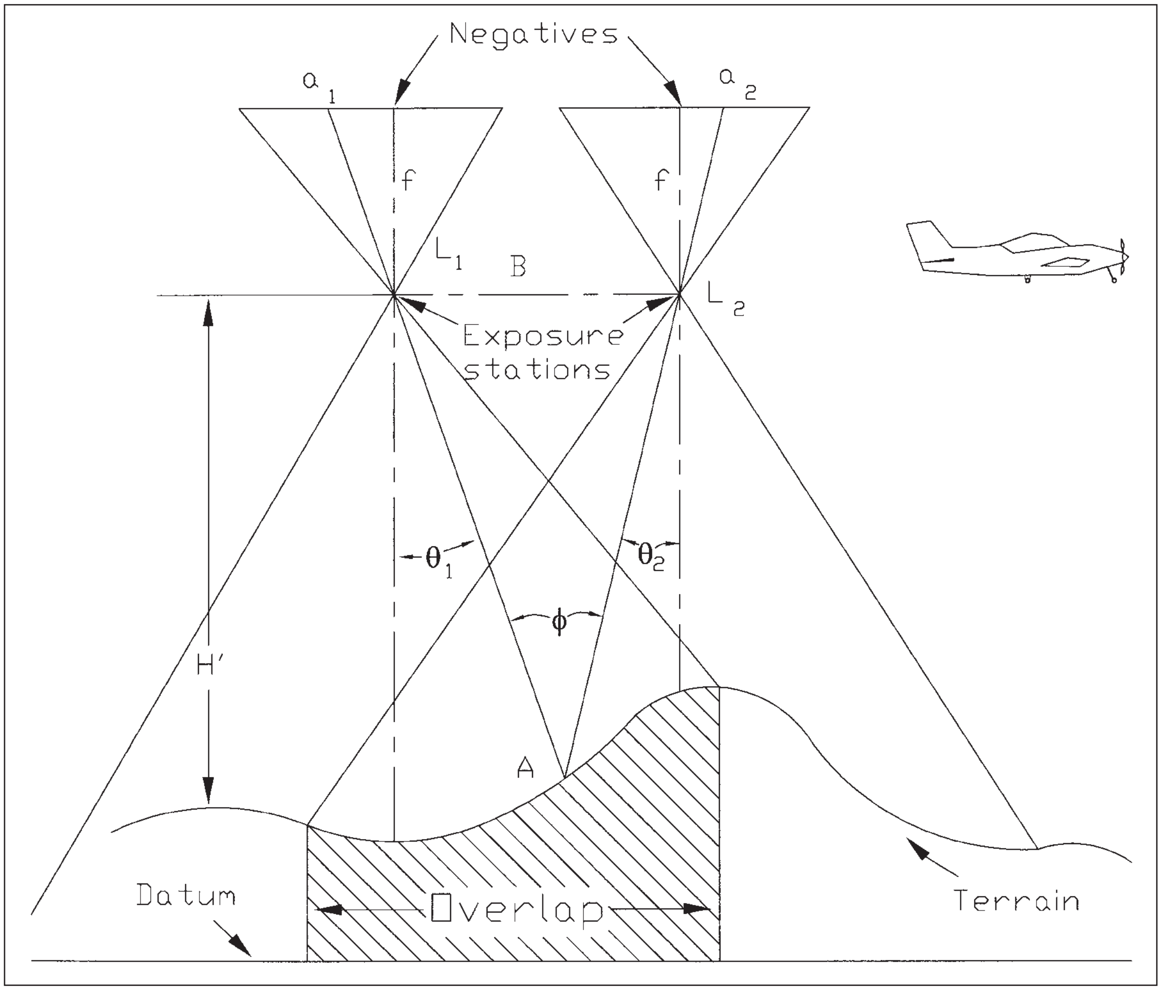

Figure A.12 The aircraft flies at a preplanned elevation (H′) above mean terrain in order to obtain the desired scale of photography. The base (B) between exposure stations (L_1 and L_2) is planned to achieve ≥60 percent overlap between exposures, allowing the terrain in the hashed area to be mapped in stereo. Stereo photogrammetry converts images from a perspective projection into an orthographic projection, as though looking straight down from infinity. The larger the angle ϕ above, the more accurate are the mapped elevations.

compiler keeps a floating dot on the ground and traces contour lines. Many other photogrammetric procedures are automated, to include the automated production of DSMs as well as pass points used in aerial triangulation. Hard-copy photos are scanned at resolutions between 7 and 25 micrometers, typically, to convert them into high-resolution digital images. Soft-copy workstations yield high-accuracy planimetric and topographic maps, as well as other photogrammetric products such as digital orthophotos, DSMs, and DTMs.

Aerial Triangulation

Aerial triangulation (AT) has traditionally been required to control a block of aerial photographs, to force mapped coordinates to fit surveyed ground control, and also to control other mapped coordinates for which surveyed ground coordinates are unknown. This traditionally has required a large number of photoidentifiable, surveyed ground control points. Photogrammetrists often use painted symbols or paneled survey targets in the shape of an X, T, or Y, prepositioned and surveyed prior to acquisition of aerial photography, to ensure that there are sufficient photoidentifiable points with known coordinates. When there are already ample photoidentifiable features, photogrammetrists may instead rely on photo points that naturally appear at desirable locations on the overlapping photography and survey those points after the photography has been flown and the film developed.

One of the objectives of AT is to determine six exterior orientation parameters for each of the aerial photographs to be used; these six parameters include *x, y,* and *z* coordinates (in airspace) of the focal point of the lens when each photograph was taken, as well as the roll, pitch, and yaw of the aircraft around the *x* axis (direction of flight), *y* axis (cross direction), and *z* axis (vertical axis).

When these photo control points are surveyed from multiple control monuments surrounding the area, the AT solution may be weakened by the fact that multiple control monuments are often inconsistent relative to each other;

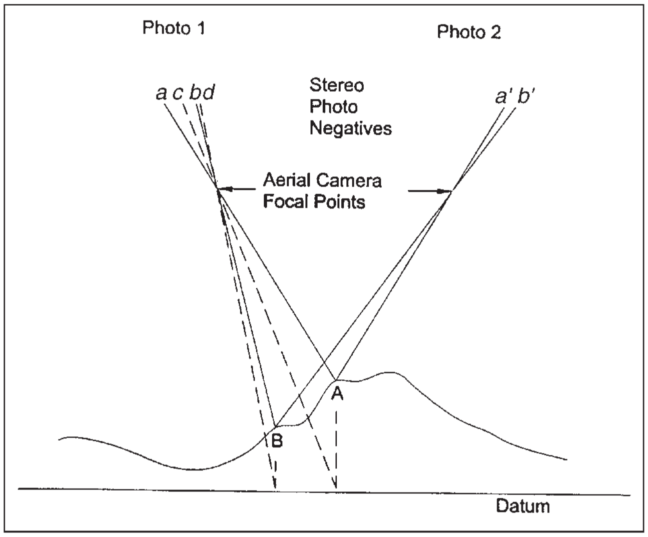

FIGURE A.13 The horizontal and vertical coordinates of A and B are mapped by the intersection of light rays through points *a* and *b* (*left photo*) and *a'* and *b'* (*right photo*) as projected through their respective focal points. As shown here, points *a* and *b* in the left photo should be at *c* and *d* in order to be orthographically correct when mapped relative to the mapping datum. Such photogrammetric corrections are not applied, pixel by pixel, to digital orthophotos; instead, a single image is draped over a digital elevation model of the bare-earth terrain.

then AT residual errors are high. It is preferred that GPS procedures be used, with a single pair of GPS base stations of highest accuracy in order to obtain consistent results, a strong AT solution, and maps that will be more accurate as a result. When this is done, then the AT residual errors are small. Experienced photogrammetrists know how to examine these residuals to determine whether the survey control is strong or weak. Fully analytical aerial triangulation (FAAT) is generally considered to yield the highest accuracy and lowest residuals.

Figures A.14 and A.15 both show an obvious variation in the roll, pitch, and yaw of the aircraft between the left and right photos. Whether variations in elevations or orientations are major or minor, a strong AT solution is required to determine the six exterior orientation parameters for each photograph. If the AT solution is strong, rays of light from the left photo will cleanly intersect with rays of light from the right photo, as shown in Figure A.14. However, if the AT solution is weak, rays of light from the left photo will not intersect with rays of light from the right photo, as shown in Figure A.15. With a weak AT solution, the 3-D coordinates of mapped points have larger error ellipses and uncertainty in derived coordinates. Therefore, a strong AT solution is the key to accurate topographic mapping.

Since the 1990s, aerial survey firms have regularly used airborne GPS and inertial measurement unit (IMU) technology to simplify the AT process, and for mapping projects over inaccessible or environmentally sensitive terrain. Airborne GPS is capable of measuring the *x, y,* and *z* coordinates directly in airspace, and IMUs are capable of measuring the roll, pitch, and yaw directly as each photograph is exposed. Some ground control points are still used for the AT process, but the numbers are reduced significantly when airborne GPS and IMU technology is properly used. However, this advanced technology is more relevant to large mapping projects than to small projects for land development applications.

Photo Scale

Photo scale is a critical factor in planning aerial photography. Photo scale is a function of the flying height above the terrain and the focal length of the mapping camera. With a mapping camera having a given focal length, the required photo scale normally establishes the flying height to be used. Subsequent scale variations in a photograph or between successive photographs are caused by variations in the terrain elevation, by variations in flying heights, or both.

Figure A.16 depicts two photographs taken over terrain having an average elevation of 400 feet above the datum and a range in elevation from 175 to 600 feet. In each case, the average photo scale is 1 inch = 200 feet.

With a 6-inch focal length camera, the flying height would be 1600 feet above mean terrain (amt). At an elevation of 175 feet, the scale would be 6-inch (0.5-feet) divided by (1600 − 175) feet, or 1 inch = 238 feet. However, at an elevation of 600 feet, the scale would be 0.5-feet divided by (1600 − 600) feet, or 1 inch = 167 feet. This is a relatively large variation in scale.

With a 12-inch focal length camera, the flying height would be 2800 feet amt. At an elevation of 175 feet, the scale would be 1 foot divided by (2800 − 175) feet, or 1 inch = 219 feet. However, at an elevation of 600 feet, the scale would be 1 foot divided by (2800 − 600) feet, or 1 inch = 183 feet. This is a relatively small variation in scale.

Normally, long-focal-length/narrow-angle lenses are better for planimetric mapping, allowing higher flying heights to be used so that views are more straight down, as looking from space. Lower flying heights with shorter-focal-length/wide-angle lenses are better for topographic mapping where elevations are critical. The standard 6-inch lens is a compromise, and subsequent tables assume that 6-inch lenses are used.

Map Scale. Table A.4 lists the photo scale and flying height commonly used for planimetric mapping at specified map scale, assuming a standard mapping camera with a 6-inch focal length and assuming an analytical plotter or soft-copy workstation is used for the mapping. Mapping photography is normally flown with a forward overlap of 60 percent between successive photos to ensure full stereoscopic coverage, and sidelap of 30 percent between adjacent flight lines to ensure continuous coverage.

Contour Interval. Table A.5 lists the photo scale and flying height necessary for topographic mapping at specified contour intervals, assuming a standard mapping camera with a 6-inch focal length.

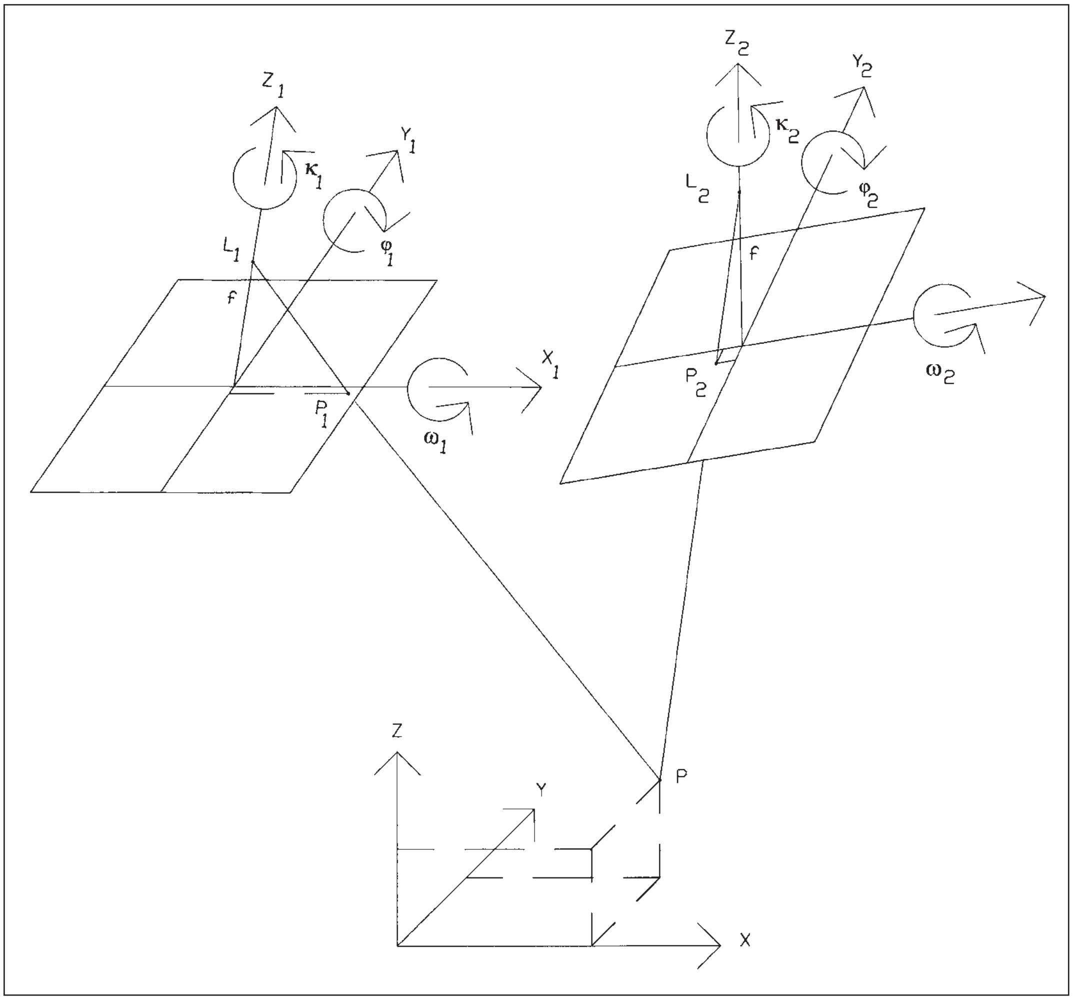

Figure A.14 With a strong AT solution, rays of light of features imaged on both photographs of a stereo pair will intersect and mapped coordinates will be accurate.

The most demanding requirement from these two tables controls the flying height to be used. For example, if maps with a horizontal scale of 1 inch = 50 feet (see Table A.4) are desired with a 1-foot contour interval (see Table A.5), then the photography should be flown at 2000 feet above mean terrain (instead of 2100 feet). Lower-altitude photography yields more accurate maps, both horizontally and vertically, but lower-altitude photography costs more than higher-altitude photography because high-altitude photography covers a larger area per photograph and requires fewer photographs and simpler aerial triangulation.

Digital Topographic Data

The introduction to this appendix included explanations of digital elevation models (DEMs), digital terrain models (DTMs), digital surface models (DSMs), mass points, breaklines, triangulated irregular networks (TINs), and contours. These are different forms of digital topographic data that are routinely produced using stereo photogrammetric techniques. Photogrammetry is so mature that procedures are well established, accuracy criteria are clear, and results are consistent, predictable, and verifiable.

Digital Orthophotos

Whereas aerial photos have perspective views of the terrain and normally include some unintentional tilt, digital orthophotos have orthographic views of the terrain (as though looking straight down on each pixel of the image from infinity) with all tilt removed. Therefore, digital orthophotos have the appearance of an aerial photograph and the metric properties of a map—with one exception. The one exception is that all features at ground level are correctly positioned, but elevated features may be displaced outward from the center of the photographs used to create the orthophotography. When a tall building, for example, appears near the center of a photograph, the orthophoto produced from that image may look like a true orthophoto without building lean; only the roof is seen. But if that same tall building appears near the edge of a 9-inch by 9-inch aerial photo, the side of the building is photographed and the roof is displaced outward

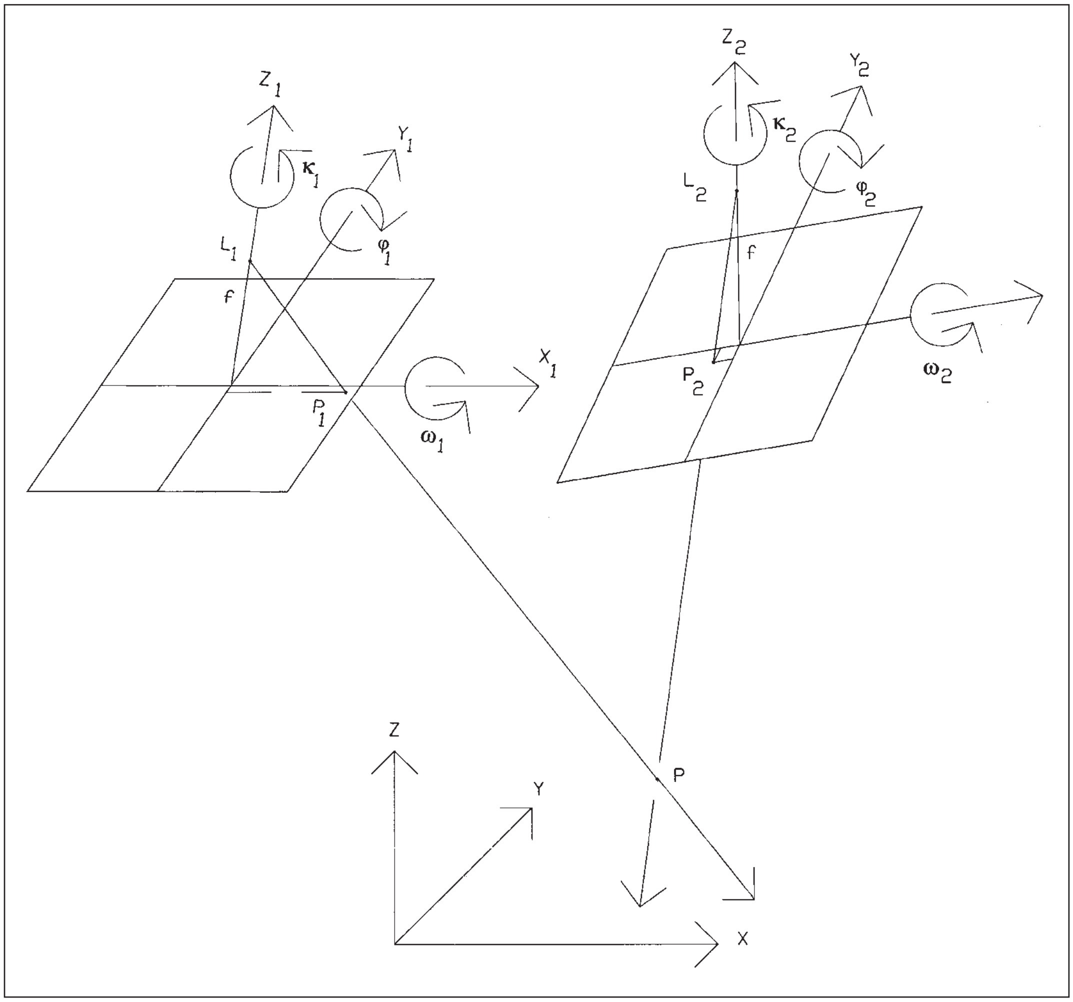

FIGURE A.15 With a weak AT solution, rays of light of features imaged on both photographs of a stereo pair will not intersect and mapped coordinates will be less accurate.

from the center of the photograph and is not located directly above the building's foundation.

There are several different technical procedures for producing digital orthophotos, but the three points most critical for land development engineers and surveyors to understand are the following:

1. Digital orthophotos are relatively inexpensive and are widely considered to be ideal as the base map for overlay of CADD and/or GIS vectors, points, and polygons developed by land development engineers and surveyors.

2. Digital orthophotos contain no elevation data. They consist of image pixels with *x* and *y* coordinates only (no *z* values).

3. Digital orthophotos are orthographically correct only for features at ground level, whereas elevated features (tops of towers, tall trees, utility poles, rooftops) are displaced outward from the centers of the digital orthophotos, as demonstrated by the orthophoto mosaic at Figure A.17. Building lean is reduced by flying from higher altitudes using cameras with longer focal lengths and narrow-angle lenses; however, even satellite images show lean in the Washington Monument, for example.

Digital orthophotos are produced by digitizing film imagery, performing aerial triangulation so as to determine the *x-y-z* coordinates of the perspective center of each image as well as its roll, pitch, and yaw, and then projecting each correctly oriented digital image over a digital terrain model of the terrain. The DTM normally includes breaklines for the top edges of bridges so that bridges are not distorted on the imagery. In mosaicing multiple orthoimages together, care is taken to ensure that seamlines are as invisible as possible and to balance the radiometry of images so they appear to be continuous, as in Figure A.17, where the three orthophoto tiles were produced from 16 different photos. However, seamlines in water are normally obvious because of differences in sun glint at the western edge of one image where it abuts the eastern edge of an adjoining image.

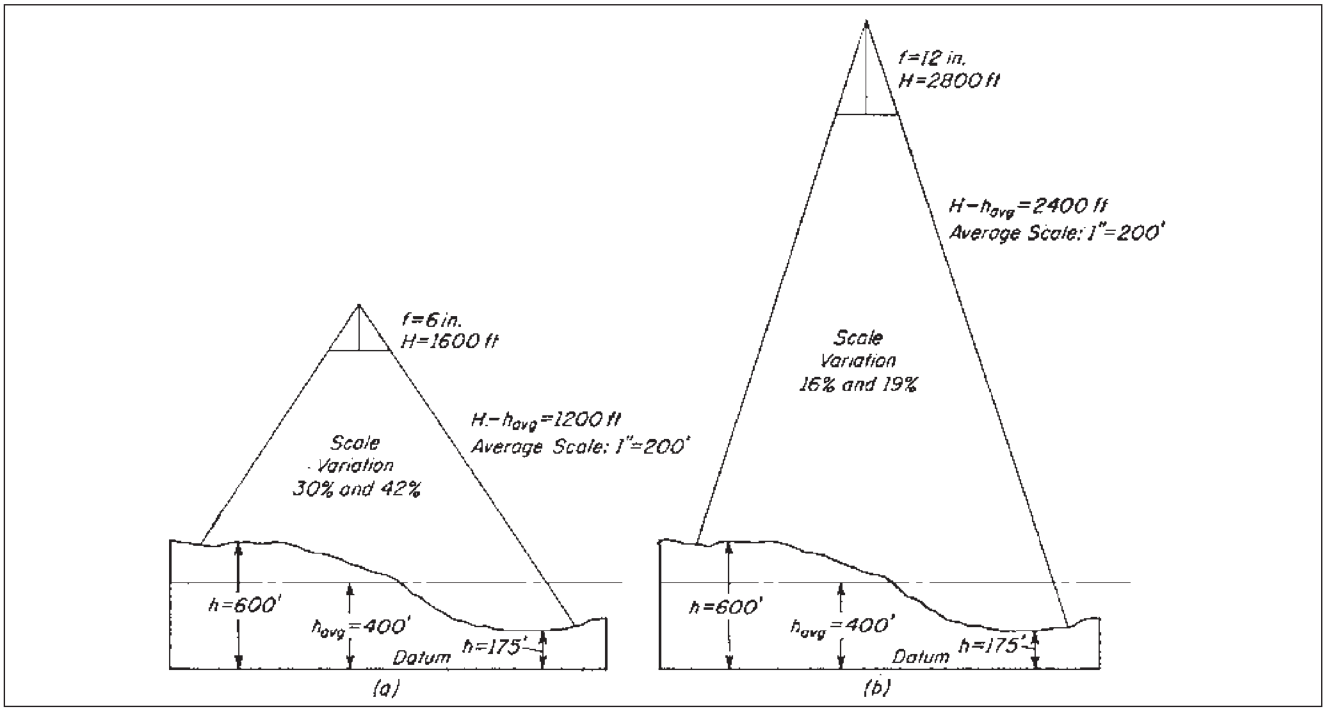

FIGURE A.16 The average scale of a typical 9-inch by 9-inch aerial photograph depends on the focal length of the camera and the variation in terrain elevations relative to the height of the aircraft above the terrain. This figure shows two ways to acquire photographs with the same average scale but acquired with cameras having 6-inch and 12-inch focal lengths flown at two different altitudes.

Oblique Aerial Imagery

Oblique aerial imagery is deliberately acquired so as to look down at the terrain from an angle (as though looking out the window of an airliner) rather than looking straight down for mapping purposes. Several competing commercial firms specialize in oblique imagery, and they normally fly with multiple cameras, each taking photographs at set intervals of time and for which the positions (*x*, *y*, and *z* coordinates) and orientations (roll, pitch, and yaw) are recorded for direct georeferencing of each image. If four cameras are used, they are oriented obliquely looking northward, southward, eastward, and westward. Some have a fifth camera looking downward.

There are more aerial cameras used today in the United States for taking oblique imagery than there are aerial mapping cameras in use for taking vertical aerial photos. The reason for this is the relatively low cost and increased interpretability of oblique imagery that make them popular for public safety applications, tax assessments, and dozens of other applications.

TABLE A.4 Photo Scale and Flying Height for Desired Map Scale

Desired Map Scale	Photo Scale	Flying Height
1 in = 20 ft	1:1680	840 ft amt
1 in = 30 ft	1:2520	1260 ft amt
1 in = 40 ft	1:3360	1680 ft amt
1 in = 50 ft	1:4200	2100 ft amt
1 in = 60 ft	1:5040	2520 ft amt
1 in = 100 ft	1:8400	4200 ft amt
1 in = 200 ft	1:16,800	8400 ft amt

TABLE A.5 Photo Scale and Flying Height for Desired Contour Interval

Desired Contour Interval	Photo Scale	Flying Height
0.5 ft	1:2000	1000 ft amt
1 ft	1:4000	2000 ft amt
2 ft	1:8000	4000 ft amt
4 ft	1:16,000	8000 ft amt
5 ft	1:20,000	10,000 ft amt

Figure A.18 shows an orthophoto of a building in Los Angeles, and Figure A.19 shows an oblique image of the same building. These images were produced by the Los Angeles Region Imagery Acquisition Consortium (LAR-IAC) for which Dewberry performed independent accuracy and quality assessments. Note the improved ability to see and understand what the building really looks like from the oblique view. From the orthophoto alone (Figure A.18), the rooftop of this tall building could have been misinterpreted as many different things, including a park, a parking garage, or a short building. The oblique image (Figure A.19) allows the number of stories to be counted. The oblique image would have significantly more value to a fire department responding to an emergency at this address or to a tax appraiser needing to assess taxes.

Figures A.20 and A.21 show the value of oblique aerial imagery for postdisaster damage assessment following Hurricane Katrina. Those communities that have acquired oblique aerial imagery are much better prepared to perform accurate and rapid postdisaster damage assessments by comparing predisaster images (Figure A.20) with postdisaster images (Figure A.21). It is important to note that reasonably accurate horizontal and vertical measurements can be made on such oblique imagery. In this example, insurance claims

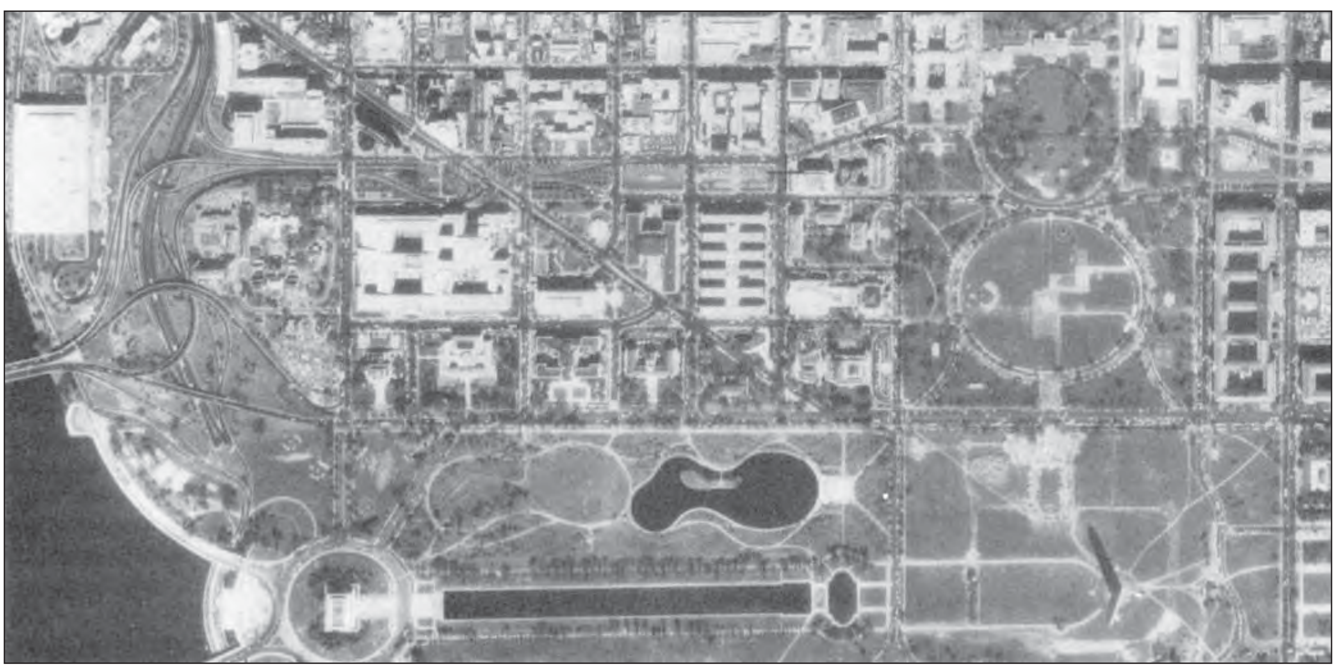

FIGURE A.17 This is a mosaic of three digital orthophoto tiles of the National Mall in Washington, D.C. The three photos were taken with a conventional aerial mapping camera. All features at the ground level are correctly positioned, but elevated features (e.g., towers, rooftops) are displaced outward from the centers of the individual photographs used to create the larger image mosaic. Near the southeast corner of this orthophoto mosaic, the Washington Monument is shown with its dark shadow pointing to the northwest, indicating that the photo was taken in the morning sometime around 10:30 A.M. The top of the monument is displaced to the southwest, whereas the monument base and ground features are correctly geopositioned. The center of the 9-inch by 9-inch photo that included the Washington Monument is located somewhere to the north-northeast of the monument itself, as opposed to the center of this image mosaic, which is northwest of the monument.

FIGURE A.18 Orthophoto of a building in Los Angeles.

were much better documented for rapid processing and approval of payments.

Major Points to Remember about Photogrammetry

- Photogrammetry is proven, mature, and well understood; results are consistent, predictable, and verifiable.
- Stereo imagery is reused for multiple applications, that is, production of digital orthophotos, planimetric mapping, and all forms of topographic mapping. Imagery can always be used to correct errors of commission and omission at a later time.
- Steps such as editing and finishing can always rely on a stereomodel to resolve discrepancies and correct errors to the highest accuracy the system provides.
- Digital imagery is commonly used for quality control and to validate data from LiDAR and other sources.
- Using stereo photogrammetry, humans manually compile breaklines and contours so that contours cross roads and streams in a manner to help humans to interpret the topography. Such contours are of cartographic quality and aesthetically pleasing, often preferred over engineering contours produced by automated techniques that are irregular and difficult to interpret.
- Using stereo photogrammetry, humans manually compile planimetric features in 2-D or topographic features in 3-D that are very accurate.
- The positional accuracy of digital orthophotos depends on the quality of the aerial triangulation process and the quality of the digital terrain model over which the imagery is orthorectified. Digital orthophotos have become the preferred base maps for nearly all forms of geospatial data.
- When automated image correlation is used for generation of a digital elevation model, the resulting surface is a digital surface model rather than a DTM. It takes a human compiler to compile photogrammetric mass points on the ground only.
- Soft-copy photogrammetry is ideal for compilation, superimposition, and display of 3-D features on top of base map imagery (digital orthophotos).

FIGURE A.19 Oblique aerial image of the same building.

FIGURE A.20 Pre-Katrina image. (Courtesy of Pictometry)

FIGURE A.21 Post-Katrina image. (Courtesy of Pictometry)

- Soft-copy photogrammetry is also ideal for cut and fill calculations and for topographic modeling of future conditions (postconstruction).

- Photogrammetric mapping is commonly used in land development design and planning to include mapping of current and future conditions. Mapping files are routinely produced in MicroStation .dgn format, AutoCAD .dwg format, or virtually any GIS format preferred. Architectural drawings can be merged to depict future conditions in 3-D and for fly-through of a proposed development.

LIGHT DETECTION AND RANGING (LIDAR)

LiDAR emits thousands of laser pulses per second to accurately map features in three dimensions. Although this section pertains to aerial mapping, the same basic technology is used with terrestrial laser scanners on the ground. Both technologies are explained in detail in *Digital Elevation Model Technologies and Applications: The DEM Users Manual*.

Airborne LiDAR sensors emit up to 150,000 laser pulses per second in some form of scanning array, as shown at Figure A.22. The most common scanning array goes back and forth sideways, relative to the direction of flight, providing a zigzag pattern of points measured on the ground. The scan angle, flying height, and pulse repetition rate determine the nominal point spacing in the cross-flight direction, whereas the scan rate, flying height, and airspeed determine the nominal point spacing in the in-flight direction. Each laser pulse has a pulse width (typically about 1 meter in diameter) and a pulse length (equivalent to the short time lapse between the time the laser pulse was turned on and the time it was turned off again); therefore, each laser pulse actually is like a cylinder of light with diameter and length. Each laser pulse may have multiple returns from features hit at different elevations, creating a point cloud of elevation points including both treetop and rooftop elevations, as well as elevations of bare-earth mass points.

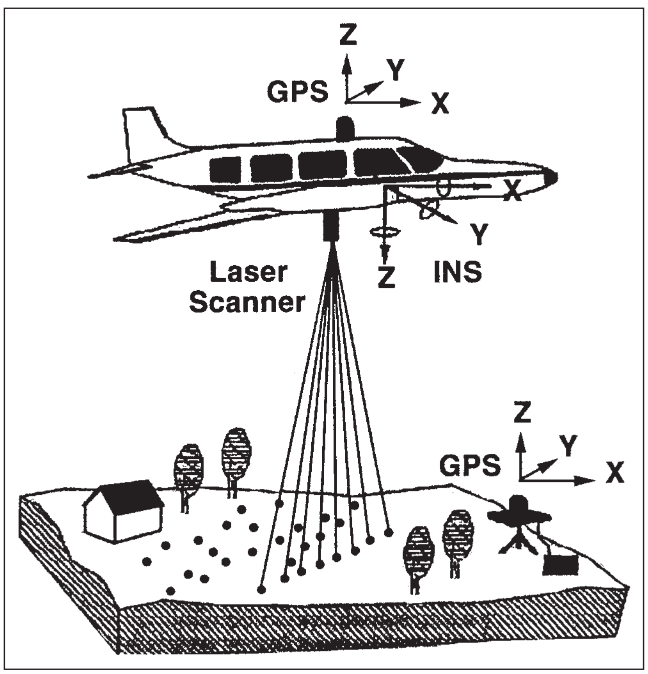

FIGURE A.22 LiDAR sensors survey up to 150,000 points per second, collecting high-density, high-accuracy elevation points—often several elevation points per square meter. Airborne GPS allows the *x-y-z* coordinates of the sensor to be known continuously. The inertial navigation system (INS) inertial measuring unit (IMU) allows the roll, pitch, and yaw of the sensor to be known continuously. The LiDAR sensor itself measures the laser scan angles and the times it takes each laser pulse to travel to the ground and reflect back to the sensor. The LiDAR point cloud data is postprocessed to classify each return as bare earth, water, vegetation, buildings, or other categories in a special laser (.LAS) file format.

Several technologies must operate correctly in order to survey high-accuracy data points:

- Airborne GPS is needed to determine the *x-y-z* coordinates of the moving sensor in the air, surveyed relative to one or more differential GPS base stations. This establishes the origin of each of the thousands of laser pulses emitted each second.

- The inertial measurement unit (IMU) directly measures the roll, pitch, and heading of the aircraft, establishing the angular orientation of the sensor about the *x*, *y*, and *z* axes in flight.

- The LiDAR sensor itself measures the scan angle of the laser pulses. Combined with IMU data, this establishes the angular orientation of each of the thousands of pulses emitted each second.

- The LiDAR sensor also measures the time necessary for each emitted pulse to reflect off the ground (or features thereon) and return to the sensor. Time translates into distance measured between the aircraft and the point being surveyed.

LiDAR sensors are capable of receiving multiple returns, up to five returns per pulse. For a sensor emitting 150,000 pulses per second, this means that the sensor must be capable of recording up to $150{,}000 \times 5 = 750{,}000$ returns per second while in flight. The first return is the top reflective surface, that is, the first thing hit by a single laser pulse; this could be a treetop, a rooftop, a ground point, or a bird in flight. When a laser pulse hits a soft target (e.g., a tree or a field of weeds), the first return represents the top or canopy of that feature. A portion of the laser light beam continues downward below the canopy and hits a tree branch, for example; this would provide a second return. Theoretically, the last return represents the bare-earth terrain, but this is often not the case. Some vegetation is so thick that no portion of the laser pulse penetrates to the ground. This is surely the case with sawgrass, mangrove, and dense forests where the canopy is so thick that a person on the ground cannot see the sky above.

A limitation of topographic LiDAR is that it normally does not penetrate water. In most cases, LiDAR pulses are absorbed by the water, so there are no returns; however, sometimes there are returns from water, but those elevations cannot be trusted. No LiDAR returns are ever thrown away, but LiDAR returns over water are classified in a water category, so they are not confused with elevations that clearly represent terrain elevations.

When the primary objective is to use LiDAR data for mapping the bare-earth DTM, then LiDAR data is acquired during leaf-off conditions so as to better penetrate vegetation. Whereas photogrammetry requires two (stereo) views of the bare-earth terrain from two different perspectives (a major disadvantage in vegetated terrain), LiDAR needs only a single pulse to penetrate between trees and/or to penetrate through vegetation that does not totally block light from above (a major advantage).

Postprocessing of LiDAR data is now largely automated, although manual editing is still required for quality control. The primary function of postprocessing is to classify each LiDAR return into one .LAS category, that is, a LiDAR data file format established by the ASPRS for classification of massive LiDAR point cloud datasets. As of 2007, the LAS classifications were as follows:

Class 0:	Created, never classified
Class 1:	Unclassified
Class 2:	Ground
Class 3:	Low vegetation
Class 4:	Medium vegetation
Class 5:	High vegetation
Class 6:	Buildings
Class 7:	Low point (noise)
Class 8:	Model key-point (mass point after thinning)
Class 9:	Water
Class 10:	*Reserved for ASPRS definition*
Class 11:	*Reserved for ASPRS definition*
Class 12:	Overlap points, nonground
Class 13:	*Reserved for ASPRS definition*
Class 14:	*Reserved for ASPRS definition,* e.g., bridge decks
Class 15:	*Reserved for ASPRS definition,* e.g., roads
Class 16-31	*Reserved for ASPRS definition*

LiDAR sensors are mounted in both fixed-wing aircraft and in helicopters. Fixed-wing aircraft are used for larger project areas; flight lines are straight and parallel, with occasional cross flights. Helicopters are used for small project areas, including narrow corridors that meander. In addition to mapping the terrain (as well as forest canopy for some applications), LiDAR is excellent for mapping and computing the volumes of stockpiles or for determining changes to the terrain as a result of strip mining or construction activities, for example. Because of the cost of deploying a LiDAR sensor on-site, there is normally a minimal cost involved (e.g., $25,000) even if all data can be acquired in a single day. Thus, for topographic mapping of a small construction site, for example, it is normally more cost effective to use photogrammetric mapping—so long as dense vegetation does not disallow the use of stereo photogrammetry for mapping the floor of a forest, for example.

Whether photogrammetry or LiDAR technology is used, products are less expensive if the client can accept digital surface models instead of digital terrain models.

LiDAR data also includes intensity imagery that looks similar to digital orthophotography but instead depicts the brightness of each laser return. As indicated, LiDAR returns on water are unreliable, and it is frequently difficult to see the

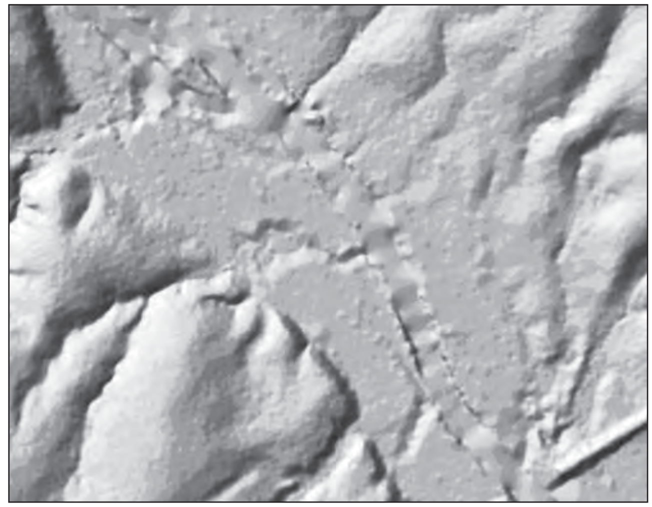

FIGURE A.23*a* LiDAR DTM does not clearly depict the shoreline of the river, yet a digital orthophoto clearly shows such shorelines.

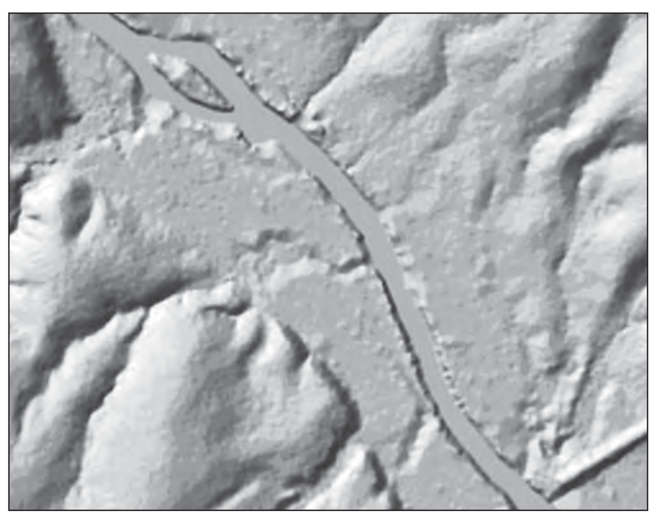

FIGURE A.23*b* The addition of 2-D breaklines from digital orthophotos can be used to burn in the water surface at elevations lower than the terrain.

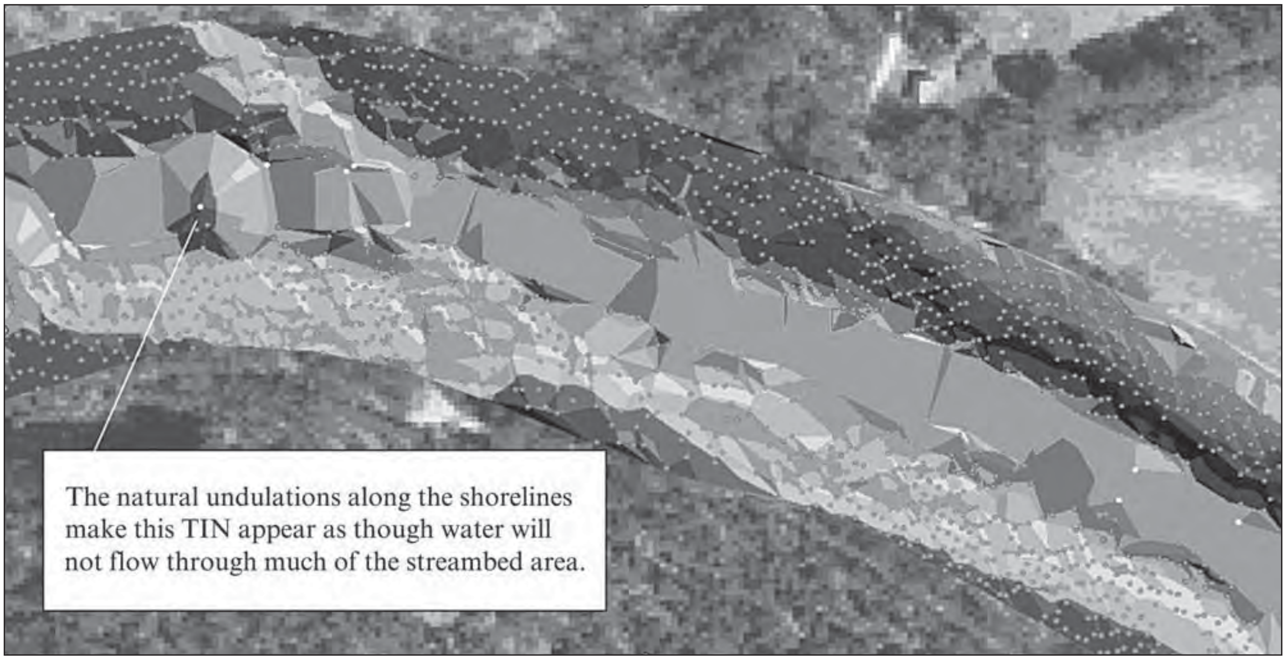

Figure A.24*a* High points on the shore on both sides of the river make this TIN look as though water cannot flow through this reach of the river.

break line at a shoreline. Whereas orthophotos may be used to generate 2-D breaklines of shorelines (see Figure A.23*a* and *b*), lidargrammetry is now used largely to generate 3-D breaklines from LiDAR intensity imagery. Per the example in Figure A.24*a* and *b*, 3-D breaklines are required for hydro-enforcement of streams to ensure that water flows downstream in hydrologic and/or hydraulic models. LiDAR "stereo mates" can be generated with base-height ratios that provide vertical exaggeration; intensity image stereo mates appear as though they are stereo photographs for compilation of 3-D breaklines and/or contours using the very same soft-copy photogrammetry tools used for compilation from stereo photographs. Although lidargrammetry is new, research has indicated that breaklines and contours produced from lidargrammetry are more accurate than breaklines and contours produced from photogrammetry, especially in terrain where vegetation obscures the stereo views required with photogrammetry.

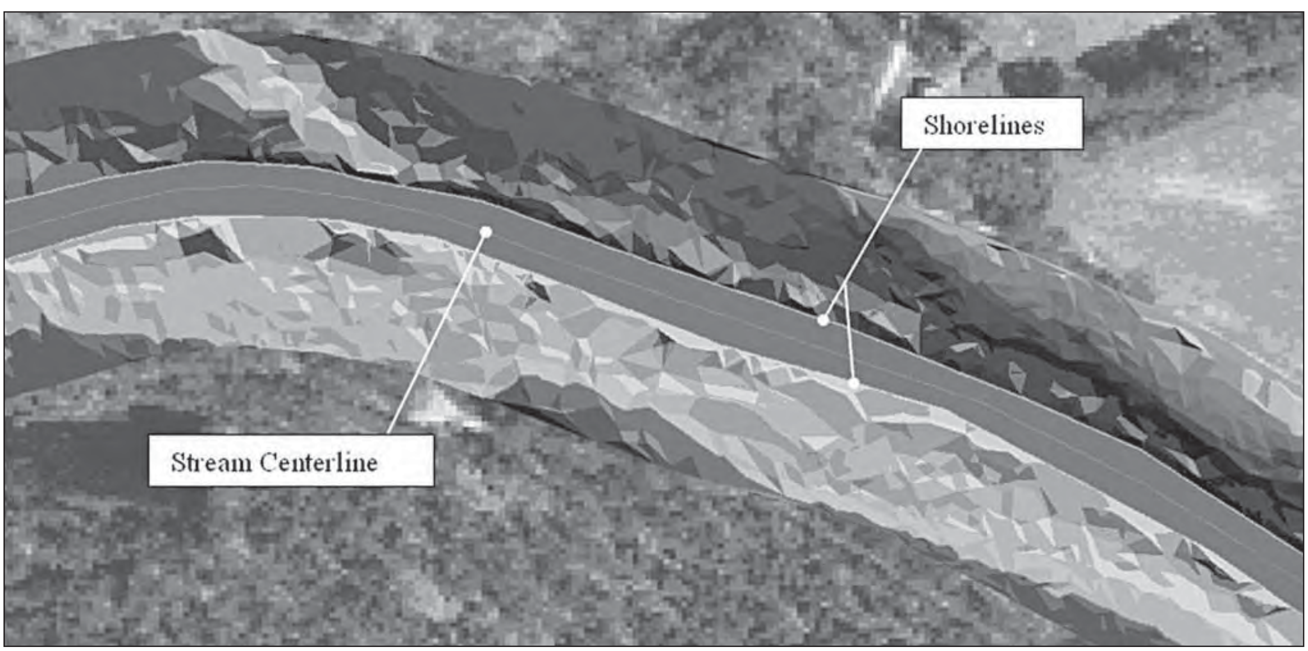

Figure A.24*b* The addition of 3-D breaklines from either photogrammetry or lidargrammetry are used to hydroenforce the TIN so that water continuously flows downstream.

The high-density, high-accuracy LiDAR mass points can be a mixed blessing. For example, they cause contours to appear very noisy and irregular. To overcome this limitation, it is common to delete LiDAR mass points on road pavements between edge-of-pavement breaklines. Also, when breaklines are generated for road edge of pavement, curbs, bottoms of drainage ditches, tops and bottoms of stream banks, and shorelines, for example, it is common to remove/reclassify LiDAR points within 1 to 2 feet of those breaklines so that the advantages of clearly defined breaklines are not offset by noisy LiDAR data points nearby.

Major Points to Remember about LiDAR

- LiDAR has an advantage over photogrammetry in generating accurate elevation datasets in dense vegetation.
- LiDAR is ideal for generation of high-density, high-accuracy elevation datasets of large areas.
- LiDAR is the technology of choice for generation of digital topographic datasets with accuracies equivalent to 1-foot and 2-foot contours (see Table A.2).
- Although LiDAR had previously been considered weak for generation of breaklines, lidargrammetry has caused a paradigm shift in such thinking.
- Tools are rapidly evolving for increased automation in the processing of LiDAR data, causing costs to lower significantly since 2000. This technology is evolving rapidly, and potential applications are limitless.
- Although automation causes costs to decrease, cost competition and demands for rapid delivery of products causes deliverables from LiDAR (and photogrammetry) to be largely unseen by human eyes prior to delivery to the customer. This increases the need for independent quality assurance/quality control (QA/QC) to ensure that each client receives the quality data that it pays for.
- Where possible, select the independent QA/QC specialist and clearly define the acceptance criteria before contracting with any vendor to produce LiDAR or photogrammetric mapping products.

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APPENDIX B

STREAM RESTORATION

Paul Makowski, PE

INTRODUCTION

Stream systems, which are complex and dynamic, form in response to conditions within the watershed. Changes in the land use, water use, and channel characteristics affect the peak flow rates, duration, and volume of stream flow, which impacts sediment transport and stream stability. In a natural process, streams will tend toward a dynamic stability by responding to changes in the system through adjustment of the stream geometry and sediment transport.

In the absence of natural or man-made controls, alterations in the watershed or within a stream can result in the stream becoming unstable as it adjusts to the changes. The tendency toward dynamic stability can result in an imbalance of the sediment transport capacity, excessive bank erosion, and degradation or aggradation of the streambed. Stream instability can result in the loss of property, habitat (benthic, aquatic, and riparian), and infrastructure. Water quality can be adversely affected by the production of excess sediment. Sediment is considered a pollutant because its volume reduces stream and lake capacities, it can cause high turbidity, and other pollutants can be absorbed by or attached to the soil particles so it is transported along with the sediment. A variety of measures can be used to stabilize a stream.

Long-term stability can be provided by hardening the streambed and banks. Hardening measures include concrete, riprap, and wire baskets (gabions). These stabilization measures confine the stream and do not allow adjustment. Hardening of the stream does not provide habitat enhancement and can create problems elsewhere in the stream system that need to be evaluated.

The goal of stream restoration and rehabilitation is to provide dynamic stability that allows the stream to change over time but maintain its geometric relationships. Both restoration and rehabilitation reestablish the general structure, function, and dynamic behavior of the stream. Although neither restoration nor rehabilitation returns the stream system to its condition prior to disturbance, restoration is a holistic approach whereby both the stream and watershed are considered. Rehabilitation actions are focused on the stream and riparian areas (FISRWG, 1998). Stream restoration, rehabilitation, and stabilization are often used interchangeably. Discussion in this chapter focuses on the elements of stream stability, which is a balance of cross section, profile, and plan form to transport sediment and water without the net long-term deposition or erosion of either the bed or banks within a stream reach (Fischenich, 2000).

PROJECT GOALS

There are a variety of reasons to initiate a stream restoration project. The most common factors that require stream restoration are loss of property, damage to infrastructure, loss of habitat, decreased habitat diversity, excessive sediment deposition, safety, or even aesthetics. Whatever the impetus for the stream restoration project, specific and realistic goals must be established to ensure that they can be achieved. Discussion of the expectations and goals must occur early in the process and must include identification and inclusion of the potential stakeholders. At a minimum, stakeholders will include the client, regulatory and permitting agencies (local, state, and federal), design team, and property owners. Additional stakeholders could include utilities, transportation agencies, environmental organizations, and citizen groups.

In developing the goals of the project, consideration must be given to the cost effectiveness of the project, whether the project fits within the budget, attainability of permits needed to allow construction, site conditions that could negatively impact construction, acceptable level of risk should the project fail, and support of the stakeholders for the project. Typical goals of a stream restoration project may include one or more of the following:

- Provide stability to the stream
- Restore aquatic and benthic habitat
- Ensure adequacy of stormwater outfalls
- Establish and expand riparian cover using native plant materials
- Improve stream temperature conditions
- Add to riffle/pool complexity
- Improve meander patterns
- Reduce sediment loads
- Increase ground water level
- Enhance aesthetics or provide a site amenity

Stakeholder input is used to establish and refine the goals and objectives of the project. Because not all stakeholders will be familiar with the components of stream restoration, an educational component may be useful. An educational component can help to avoid potential misunderstanding. For example, stream restoration plantings may have a "too natural" appearance. It may be necessary to adjust the planting plan to suit individual taste. Raising the ground water level may lead to complaints of wet yards. The educational component should include field visits to the project site, to other restoration projects under construction, and to completed projects.

There may be stakeholders who will oppose one or more goals or even the project itself. A frequent objection to stream restoration projects is the degree of disruption to the environment that will occur. The loss of, or damage to, mature trees is a frequent concern, as are temporary aquatic impacts related to construction activities. The concerns of the stakeholders must be adequately addressed by members of the design team. The goals of the restoration project may need to be modified to address stakeholder concerns. However, to be considered viable, the project must also meet the original objectives. Monitoring of the site during and following construction can be employed to assess the effectiveness of the measures used to control potential collateral impacts.

DESIGN APPROACH

Restoration measures are designed to return dynamic stability and environmental function to the streams. These measures tend to be self-maintaining because they have been developed to work with the stream, but they are not necessarily maintenance free. To achieve dynamic stability, the design approach is to provide a geometry (cross section, profile, and plan form) that the stream will tend to reach. Restoration measures include bioengineering (vegetation), stream shaping and realignment, and revetments (grade control measures and redirective techniques). The methods to be used for stream restoration must be selected based on the following considerations:

- Stated project objectives
- Technically sound design
- Desired level of protection
- Risk of failure
- Cost effectiveness
- Durability
- Required permits
- Constructability
- Construction budget

The initial step in the design is to gather available information from existing sources. Available data can include mapping (topographic, land use, soils, geologic, and property boundaries), aerial photographs, watershed studies or plans, flood insurance studies, and stream gauge information. Much of the information may be available in a GIS format, which can facilitate the review process. After reviewing the data, a site assessment must be conducted. During the site assessment, the entire segment of stream to be restored should be observed, preferably from within the channel. In addition, the overbank areas on either side of the stream need to be observed. Elements to be observed during the site assessment should include areas of stability and instability, natural or man-made controls, indications of previous stabilization or alteration, and potential constraints. Possible constraints to the proposed restoration may include utilities, private property, buildings, roadways, wetlands, unique vegetation or habitat, or significant trees. Field observations should be photographed and their location recorded on a site map. To obtain a more complete understanding of the stream segment to be restored, the stream upstream and downstream of the project should also be observed. The distance to be observed can vary depending on the stream characteristics but should include a minimum of two meander wavelengths or 20 to 30 times the stream width.

Depending on the quality and age of the topographic information, an engineering survey may be needed to provide or supplement the required information. The survey should include potential constraints, geomorphologic characteristics (described later) and permit-related information.

The site assessment will include collection of detailed information required to evaluate the existing conditions based on the stream's geomorphologic characteristics. These characteristics include the following:

- Profile elevations
  - Thalweg (the line connecting the lowest points along the streambed)
  - Edge of water
  - Bankfull
  - Floodplain, top of bank or terrace
  - Pool and riffle
  - Valley
- Plan View
  - Sinuosity
  - Meander geometry
- Cross section
  - Bankfull width
  - Bankfull elevation
  - Floodplain, top of bank or terrace elevation
  - Flood-prone width
  - Flood-prone elevation
- Channel material
  - Bed
  - Bank
  - Bar

A reference condition, which has similar geomorphologic characteristics to the proposed restoration, can be used as a design template for the proposed design. The reference condition can be found either in a stable reach along the stream to be restored or in a neighboring stream that shares hydrologic, geologic, geomorphologic, and physiographic characteristics (FISRWG, 1998). Published literature may contain information that can be used to establish reference conditions. The reference condition will be used to develop the profile, plan, and cross-section relationships for the proposed design.

The design process includes the development of the flow rates for the stream. Flow rates can be obtained from previous studies or developed from regional regression equations, analysis of historical stream flow data, and hydrologic modeling. For comparison, flow rates should be developed using more than one method. The design flow rate is related to the degree of protection that is required and the acceptable level of risk of failure. Usually a range of flow rates are developed and evaluated. Typical flow rates correspond to storms with return intervals of 1, 2, 5, 10, 25, 50, and 100 years. The 100-year flow rate is related to the Flood Insurance Program of the Federal Emergency Management Agency (FEMA) and must be used in a hydraulic model, such as HEC-RAS (USACE, 2002) to assess whether the proposed stream restoration measures would have any effect on the water surface elevation and ensure that there were no adverse impacts to roadways, bridges, buildings, or property. The restoration can impact the water surface elevation by increasing the roughness, decreasing the slope or cross-sectional area, or raising the profile of the stream relative to the overbank area.

The bankfull flow rate is used to represent the flow rate that shapes the stream. In natural streams, the 2-year flow rate is used as the bankfull discharge in the eastern half of the United States. However, flow rates corresponding to return frequencies of between 1 and 10 years may be appropriate (USACE, 1994a). Rosgen and Silvey (1996) reference the bankfull discharge as having a return frequency of 1.5 years. It was also observed that, from moderately developed watersheds, bankfull occurs as frequently as three to four times per year (Schueler, 1987). The bankfull stage can be estimated through field methods (Rosgen and Silvey, 1996). However, incised streams that are not in dynamic equilibrium will not have reliable indicators of the bankfull stage. Having multiple bankfull elevations along the profile of the stream allows various flow rates to be used in the hydraulic model to estimate a flow rate that best represents the bankfull flow rate. The estimated flow should then be compared to published bankfull flow rates appropriate for the level of development in the watershed. Hydrologic models such as HEC-HMS (USACE, 2006) allow a variety of land use scenarios to be developed for the watershed. For example, a hydrologic model could be used estimate flow rates associated with the present, future, or some other stage of development, which can be used for the restoration design.

Dynamic stability is a function of stream geometry, sediment load, flow rate, and bed and bank materials. Therefore, it is necessary to develop an understanding of the sediment stability as part of the restoration. The size distribution of sediment can be obtained using particle count or by collecting sediment samples and conducting a particle size analysis. The sediment should be characterized at multiple locations along the section to be restored, taking care to collect samples at riffles and pools. Sediment stability is assessed by comparing the critical shear stress of the sediment to the shear of the flow in the stream. The critical shear stress of the sediment is that when exceeded by the shear stress produced by the stream, movement of sediment will occur. Hydraulic models such as HEC-RAS calculate the shear stress produced by the stream. Because the stream needs to remain stable throughout a range of flow rates, additional bank and bed protection measures may be necessary.

Protection of the streambed and profile is provided by grade control structures, which are divided into two categories. Bed control structures provide hardened points to resist erosion. Hydraulic control structures reduce the energy slope by providing a stable drop.

Bank protection practices are divided into three categories. Bioengineering is a vegetative method that stabilizes the bank by providing a root system that binds soil particles, which increases the shear strength of the bank. The vegetation also reduces the flow velocity acting against the soil. When using bioengineering practices, it is important to provide a stable toe to prevent undercutting of the bank. Redirective techniques reduce the shear stresses against the stream bank by directing the flow into the center of the channel. Redirective measures frequently cause sediment deposition between the structures, which adds to the protection of the stream bank. Resistive methods are structures constructed to resist shear stresses. Resistive methods may cover the bank or be limited to the toe.

A partial list of potential bank and bed protection measures follows. Common protection measures are presented as Figure B.1.

- Grade control
  - Bed control structure
    - Rock cross vanes
    - Rock "W"-weirs
    - Rock weirs
    - Rock sills
  - Hydraulic control
    - Drop structures
    - Log drops
    - Step pools
    - "V" log drops
    - Rock chutes
- Bank protection
  - Bioengineering (see Chapter 27 for additional information/details)
    - Native plant material
    - Natural fiber matting
    - Live stakes
    - Natural fiber rolls
    - Live fascines
    - Live soil lifts
    - Brush mattresses
    - Branch layering
  - Redirective
    - Rock vanes
    - "J"-hook vanes
    - Wing deflectors
    - Dikes
    - Log vanes
    - Bendway weirs
  - Resistive
    - Brush bundles (cedar tree revetments)
    - Rootwads
    - Imbricated rock walls (stacked stone walls)
    - Crib walls
    - Rock toe protection
    - Log bundles
    - Riprap
    - Gabions mattresses
    - Articulated concrete blocks
    - Interlocking concrete jacks

These bank and bed protection measures can be used either alone (for small stabilization projects) or in combination. When selecting a method, the durability, performance and environmental setting of the construction material needs to be considered. Design will include a number of considerations such as sizing the rock, specifying the filter material, determining extent of coverage, developing spacing of the structures, and establishing how the structures are tied in to the soil interface to prevent erosion. With respect to bioengineering practices, the survivability of the plant materials is enhanced by the use of native vegetation. The native vegetation, which has a natural appearance, also improves the aesthetics and habitat of the area. Specifying native vegetation ensures that the plants are suited for hydrologic and temperature extremes, animal foraging, insects, and disease. To enhance the survivability of the plant material, irrigation may be required.

Figure B.2 shows bank and bed protection measures in a recently restored stream. Figure B.2*a* is looking upstream and has a rock weir, rock cross vane, imbricated rock wall, and live stakes. Looking downstream, Figure B.2*b* shows a rock vane, rock cross vane, imbricated rock wall, coir roll, and erosion control matting.

In some instances, it is necessary to consider incorporation of traditional engineering solutions into the stream restoration design. For example, a drop inlet can be used to lower a storm drain outfall to be compatible with an incised channel. The drop inlet dissipates the energy of the storm drain and allows the redirection of the outlet so that it is more closely oriented to the flow in the receiving stream (rather than directed at the opposite bank). Energy dissipators (Thompson and Kilgore, 2006) are used at storm drain outlets to decrease the energy entering the stream, or, for smaller streams, they can be used to dissipate the energy within the stream. Utilities crossing beneath the stream require special protection measures such as encasement, drop structures, hardening, or a combination of these.

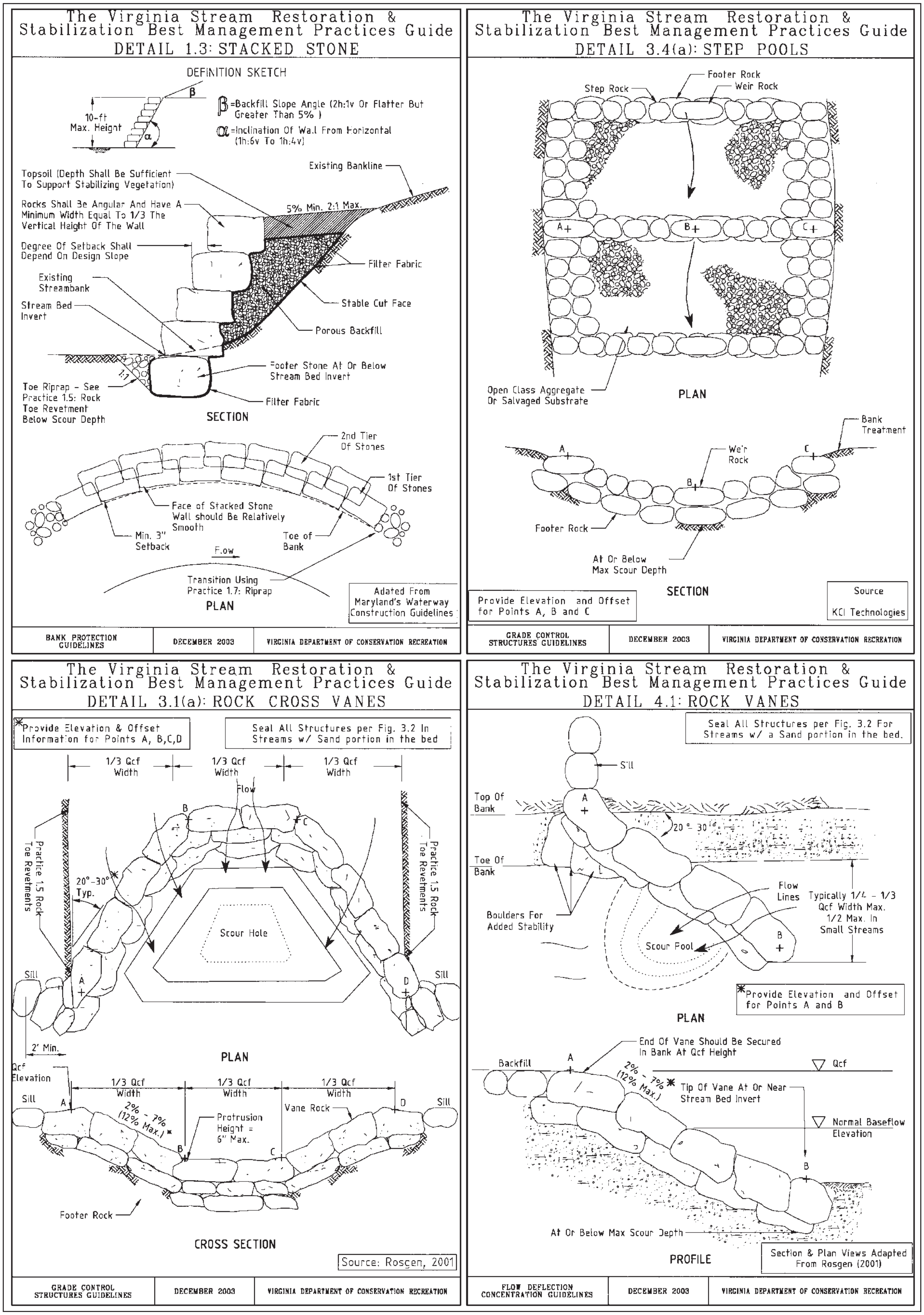

FIGURE B.1 Common streambed and bank protection measures.

FIGURE B.2 Recently constructed stream restoration project illustrating bank and bed protection measures (*a*) looking upstream and (*b*) looking downstream. (Photo courtesy of Paul Makowski).

Stream restoration should be treated as a detailed engineering design and incorporated into a drawing set. The drawings should include sufficient information to allow the project to be constructed as well as to satisfy the requirements of the owner and the reviewing agencies. Construction-related information includes material specification and installation requirements. The amount of information to be included in the drawing set is dependent on the complexity of the project. However, the minimum amount of information to be included in the drawings is as follows:

- Erosion and sediment (E&S) control
  - □ Limits of disturbance
  - □ Trees to be removed and protected
  - □ Construction access
  - □ Staging, storage, and material stockpile areas
  - □ E&S control practices
  - □ Dewatering technique
  - □ Site restoration (stabilization)
- Grading plan
  - □ Existing and proposed contours
  - □ Limits of grading and disturbance
  - □ Proposed revetments and stabilization measures
  - □ Construction notes
- Geometric plan
  - □ Benchmark
  - □ Traverse coordinates
  - □ Horizontal and vertical datum
  - □ Property information
  - □ Source of the survey
  - □ Line and curve, PC, PT data
  - □ Stream centerline stationing
- Profile
  - □ Existing and proposed ground elevations along the proposed centerline
  - □ Existing invert
  - □ Proposed grade control station and elevation
- Cross sections
  - □ Existing ground
  - □ Proposed cross-sectional shape with dimensions and side slopes
- Planting (landscaping) plan
  - □ Plant location based on hydrophilic and sunlight preference
  - □ Plant material list and specifications (over- and understory trees, shrubs, herbaceous plants, seed)
  - □ Plant installation description
  - □ Matting and mulching specifications
  - □ Guarantee or replacement information
  - □ Abatement and control plan for undesirable plant species
- Details

The drawing set may include items related to the stream restoration project such as utility relocation or stabilization requirements, storm drain improvements, energy dissipators, floodplain information, pedestrian bridges, low-water crossings, fencing, and retaining walls. A plan view of a stream restoration is shown in Figure B.3 and the profile is shown in Figure B.4.

Following the completion of the design, the quantity of items contained within the drawings may be developed. A construction cost estimate can be made from the item quantities and unit costs. Cost information can be obtained from construction cost data sources such as those contained in RS Means Company publications. Cost data may also be available from state and local agencies, such as transportation and natural resources departments, in either a published format or as bid tabulations.

CONSTRUCTION

After the stream restoration design documents have been prepared, construction estimates can be solicited from qualified contractors. The uniqueness of stream restoration construction requires that the contractors be qualified for this specialized work. They must have access to and have experience in the use of proper equipment. It is necessary to obtain references from the contractors. The references should be contacted to determine how the construction proceeded and whether there were any problems or concerns. A field visit to the location of a completed project is helpful to assess the workmanship of the contractor. The completed project should possess characteristics similar to those of the proposed restoration. Close attention should be paid to the condition of the revetments and plant material.

The design engineer should be available for the prebid meeting to respond to questions from the contractor. The contractor should visit the site prior to the prebid meeting, or, alternatively, the meeting could be held on site. Prior to preparation of the bid, the contractor should be made aware of any design, permit requirement, concurrent construction activities, utility crossings, or other restrictions that will affect construction and may affect the cost. For example, the stream may have a time-of-year restriction that prohibits work in the water during specific times of the year. Stockpile, equipment storage area, site access, vegetation preservation, and sensitive areas also need to be identified when on-site.

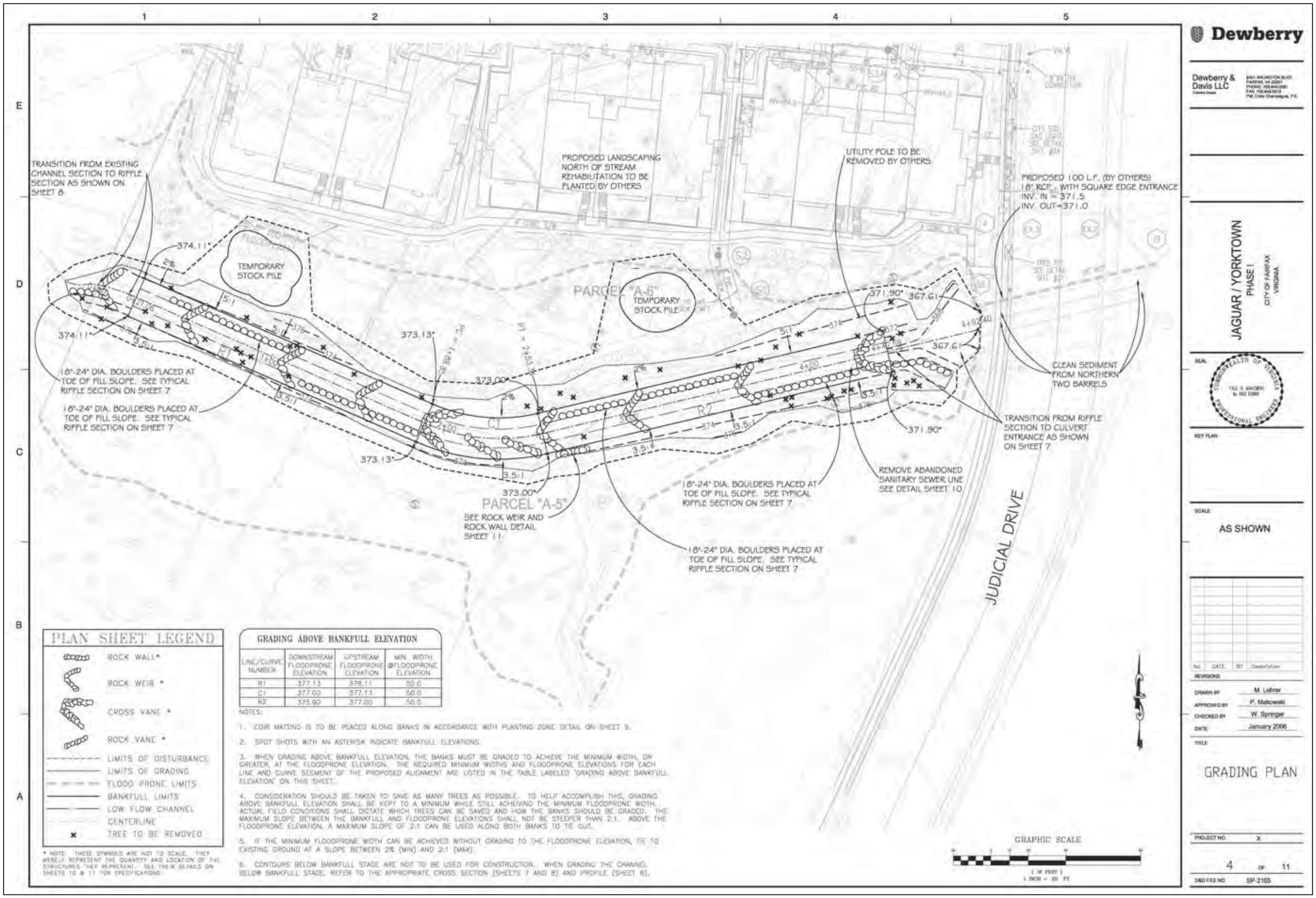

FIGURE B.3 Plan view of a stream restoration. (Courtesy of JCE, Inc., Alexandria, VA)

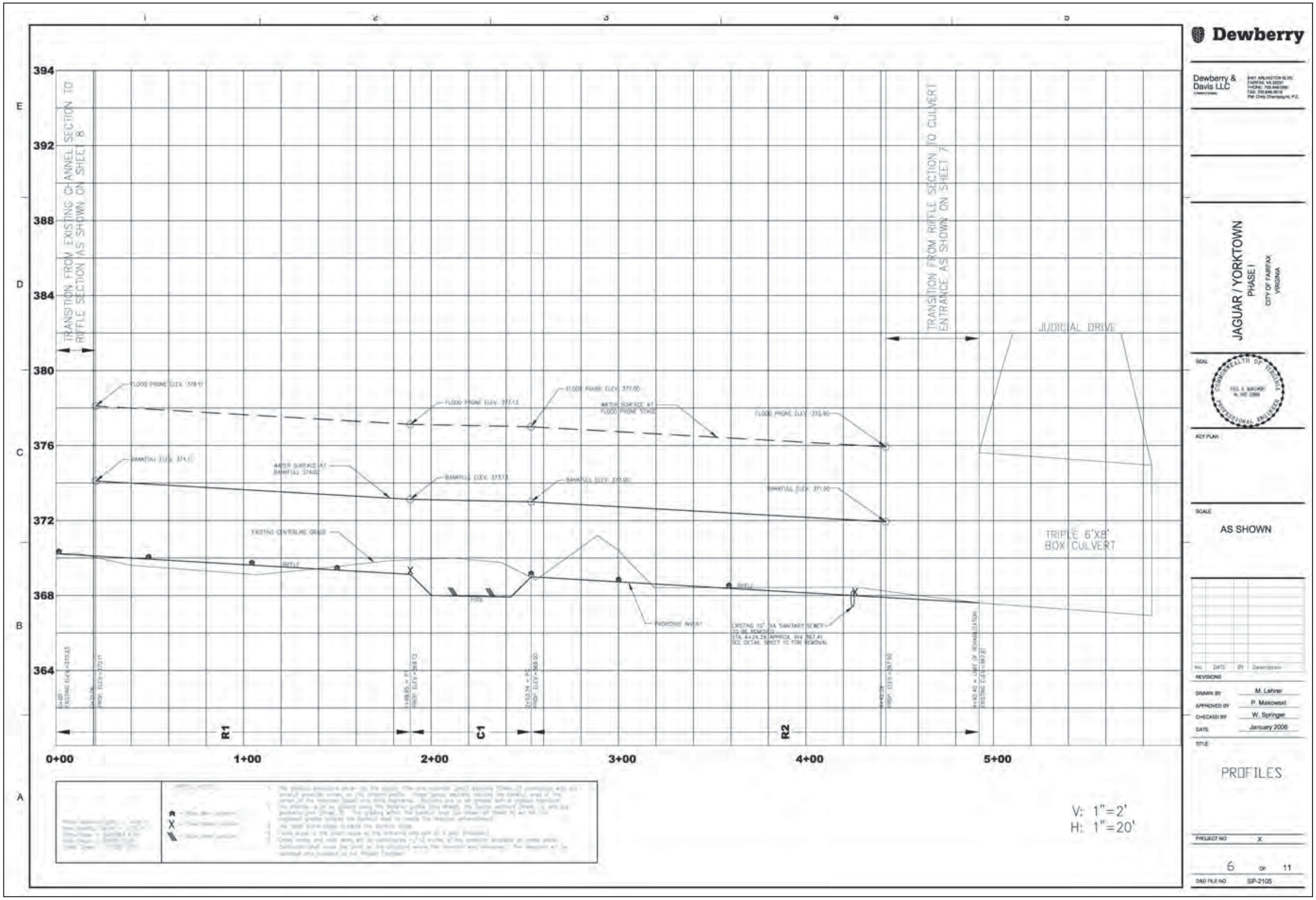

Figure B.4 Profile of the stream restoration shown in Figure B.3. (Courtesy of JCE, Inc., Alexandria, VA)

Construction observation should be provided by the design engineer. Being on-site, the design engineer can determine whether the restoration is constructed as intended and can be available to respond to the contractor's questions. The design engineer can schedule time to be on-site depending on the pace and complexity of construction. Each site visit and request for information from the contractor should be recorded as a field report.

It may be a requirement of the permit that construction occurs either "in the dry" or that the water quality be monitored so that it does not exceed an established value. Turbidity is a water quality metric that is typically monitored. Depending on the size of the stream, working in the dry may be easier. The pump-around technique works best in smaller streams. In this technique, a sandbag cofferdam is constructed at the upstream end of the section of stream under construction. The purpose of the cofferdam is to keep water from entering the work area and to back up the stream flow so that it can be pumped around the work area. The flow should be discharged into an area that has been stabilized so that pumped flow does not suspend sediment and affect the downstream water quality. Due to the cost of rental and operation, the pump-around technique is typically used for stream flow rates of several cubic feet per second (cfs) or less. Larger flow rates require the use of the diversion technique in which a cofferdam is constructed to allow a portion of the stream channel to convey the flow while a portion remains dry. With both the pump-around and diversion techniques, the cofferdams are relocated to allow construction to proceed. Working in a stream environment can yield water levels exceeding safe conditions within 30 minutes following the onset of a storm event. Therefore, the evacuation of personnel and equipment from the stream is a safety and economic issue that requires an evacuation plan. The weather conditions need to be frequently monitored to ensure personnel safety.

A typical construction sequence would include the following:

1. Set up cofferdams within the daily work zone.
2. Place the pumping system or construct the diversion.
3. Survey grade control and revetments.
4. Start rough grading operations.
5. Stockpile and haul soil.
6. Install revetments.
7. Set invert elevation and construct thalweg.
8. Perform final grade.
9. Amend soil as needed.
10. Seed graded area.
11. Install erosion control matting.
12. Stabilize upland disturbance and stockpile areas.
13. Remove pumps and cofferdams.

Because the construction sequence must be completed on a daily basis, the construction project manager is required to coordinate and orchestrate multiple activities and crews in a confined workspace.

Following the completion of the grading and installation of the temporary and permanent stabilization measures, the plant material is installed. For survivability of the plant material, it is required that live stakes be installed when they are dormant; therefore, depending on the time of year in which the restoration is complete, the contractor may need to return to install the live stakes. Other plant material may be installed throughout the year but may require irrigation.

A photograph of a recently completed stream restoration (looking upstream) is shown as Figure B.5*a*. From the same vantage, Figure B.5*b* shows the same stream after two growing seasons.

Prior to the removal of sediment control measures and restoration (stabilization) of the site access, stockpile, and equipment storage areas, the restoration construction should be reviewed and documented in a punch list. Deficiencies on the punch list should be repaired before acceptance of the project. The guarantee (or monitoring) period (if any) should start after the project has been accepted.

MAINTENANCE

Although stream restoration projects are designed and constructed to be self-maintaining, they are not maintenance free. Although the restored stream is most vulnerable immediately following construction, maintenance may be required at any time. Without timely maintenance, the restoration project may not continue to meet the goals and objectives of the project. Therefore, a monitoring plan must be developed to assess the condition of the restoration project, whether maintenance is required, and if the project meets the stated project goals and objectives. If monitoring is a regulatory requirement, the monitoring frequency, parameters, protocol, and duration will be detailed in the permit. A budget should be established for expenditures associated with routine maintenance.

Typically, stream restoration projects are inspected annually to determine maintenance requirements. The frequency of inspection can be adjusted depending on the results. The frequency can be decreased if few problems are found or the problems are minor. Conversely, the frequency may need to be increased if numerous problems are found or if the problems are major. In addition to the routine inspections, it is recommended that the stream be inspected after major flooding events. The inspector should look for indications that the restoration is not functioning as intended, such as:

- Scour
- Undercutting of the banks
- Deposition
- Movement of structural components within any revetments

- Dead or missing plant material
- Vandalism
- Trash dumping
- Mowing within the buffer
- Blockages within the stream channel
- Presence of invasive plants

Plant material must tolerate hydrologic and temperature extremes, animal foraging, insects, and disease. Without vegetation, the stability of the stream may be compromised, as will the other environmental benefits. Replacement of missing or compromised plant material should occur as soon as possible. A determination must be made as to why the plant material failed initially so that the cause of failure is addressed and the replanted material is afforded an opportunity to successfully establish. Typical causes of failure of plant material include animal browse, insect damage, improper plant selection with respect to sunlight preference or hydrophilic zone, drought or flood conditions, improper installation, soil conditions, competition from invasive plants, vandalism, or mowing.

Movement of sediment will occur in stream restoration projects, especially immediately following construction and during large runoff events. However, the erosion or deposition of the streambed or bank should not be excessive. Erosion can be considered excessive if it results in failure of a slope or revetment. Excessive deposition may fill in pools, cover plant material with sediment, or adversely affect the hydraulics. The cause of the excessive erosion or deposition must be determined before any decision on how to proceed can be made. The best course of action may be to monitor the situation and determine whether the condition is deteriorating, staying the same, or improving. If the condition is worsening, a plan should be developed to address the problem. Typical questions include:

- What is the rate and severity of failure?
- Is the failure localized or widespread?
- What are the consequences of inaction?
- Will the failure affect upstream and downstream areas? If so, what are the effects?
- What are potential solutions?
- Is large or heavy equipment needed to implement the potential solutions?
- Is there site access?
- How much time is needed to implement the solution?
- What is the available budget?

The responses to these questions will determine the appropriate course of action. However, budgetary limitations may require creative solutions. It is beneficial to apply lessons learned from the design process and previous projects to development of potential solutions.

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FIGURE B.5 A stream restoration project (*a*) immediately following reconstruction and (*b*) after two growing seasons. (Photo courtesy of Paul Makowski)

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APPENDIX C

SOILS

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INTRODUCTION

Proper, thoughtful, and deliberate site selection can often be paramount in creating a successful development project. The owner/land developer does extensive research to choose a site that can yield the greatest return on investment. Such research typically involves an analysis of site location, size, shape, and topography. Subsurface soil investigation is one of the most important, yet most commonly overlooked, factors in the success of a project; it is often one of the last items on the developer's check list. Many times it is the least funded aspect as well.

The purpose of this chapter is to familiarize land development engineers with some of the basic soils or geotechnical issues that are likely to be encountered during the planning, design, and alteration of the site for the intended use. Knowledge of the basic properties of soil and its physical characteristics is helpful to land development engineers when planning site grading, stormwater management structures, roadway and parking area subgrades, retaining structures, and foundations for all types of structures. Also included in this chapter are typical geotechnical problems that may be encountered during site development, an overview of the engineering properties of soils, and guidance to aid in the understanding of soils reports and geotechnical engineering design parameters provided by geotechnical engineers.

Many questions need to be addressed prior to choosing a site, including whether the local community has experienced landslides, earthquakes, sinkholes, swelling and shrinking soils, and other geohazards. Although this chapter discusses these issues, retention of an experienced geotechnical engineer as part of the project design and construction team can help limit some of the problems.

SOIL CONSIDERATIONS: UNDERSTANDING YOUR SITE

From an engineering perspective, subsurface soils are the organic and inorganic materials of the earth's surface that are capable of being displaced by shovel or nominal mechanical efforts and may provide the foundation and support of the proposed project. Soil is an integral part of the design analysis and construction activities and is often used as a foundation in its natural, undisturbed state or as a construction material for fill, backfill, and embankments. The behavior of soil may vary depending on the situation. Many structural failures have been attributed to not properly addressing subsurface conditions or predicting soil behavior. The engineer should be concerned with what types of soils lie below the ground surface and their associated properties and characteristics including strength, compressibility, permeability, grain size distribution, and moisture content.

Besides those methods that describe and indicate soil properties and parameters for engineering purposes, other methods of describing, categorizing, and identifying soils based on the interests of other professions are available to assist engineers. Soil scientists (agronomists) are interested in the origin, distribution, and classification of soil for agricultural purposes. Geology is the study of the origin, history, and structure of the earth with a focus on rock and rock formations. While geologists typically consider soil as the weathering product of rocks, agronomists' interest in soil is obviously related to agriculture. Soils and their properties are often described by terms specific to these two disciplines, and it is helpful if engineers can relate their terms to engineering interests. Geotechnical engineers look at the strength, compressibility, and permeability of the soils at sites in order to make assessments about their stability, settlement, and drainage characteristics as related to the proposed construction.

Strength and compressibility of the soils are the primary characteristics that are important in foundations of structures (buildings, retaining walls, and headwalls). Permeability and strength are soil characteristics that are important when designing stormwater management facilities, engineering slopes, and changing the topography at the site. The strength characteristics of soils are important to predict slope behavior and prevent slope failures. Erodibility is another soil characteristic that is important for evaluation of erosion potential and determination of soil erosion control measures. Buildings founded on weak soils can result in catastrophic structural failures. Buildings founded on compressible soils can experience excessive settlement, resulting in expensive repairs. The success of infiltration facilities, common in low-impact development (LID) approaches to site design, hinges on the permeability of underlying soil strata. A thorough understanding of soil properties—strength, compressibility, and permeability—allows land development engineers to accurately asses the feasibility of various design options and, ultimately, to accurately design, detail, and specify site features.

Geotechnical engineering is the branch of civil engineering that involves the design and use of soil and rock in engineered construction; it is involved in all types of construction in, on, or of the earth. With specific knowledge of the soil properties of a site, the geotechnical engineer can design soil support and fill projects while predicting their behavior comparable to other engineering materials such as concrete or steel. Some projects may require careful consideration of rock and ground water conditions, and geotechnical engineers also need to understand the geology, hydrology, and local problem soils in the vicinity of a given site. Typically, the developer hires a geotechnical engineer who has experience with similar developments, is familiar with the project region, and is accustomed to the requirements of the permitting jurisdiction.

Prior to developing a site, the developer should be familiar with conditions both above and below the surface of the site. Will it be necessary to cut or fill the site, or import a significant amount of soil to grade the site for the proposed project? If the soils below the surface are not investigated appropriately and foundations designed properly, excessive and damaging differential settlements may occur.

SOIL PROPERTIES AND CHARACTERISTICS

Fundamental Properties and Parameters

To establish a consistent vernacular for use throughout this chapter, a brief glossary is provided to define common soil terms and review the fundamental soil properties and parameters used in the engineering industry.

Atterberg Limits: A measure of the consistency of cohesive soils represented by the moisture content associated with the shrinkage limit, plastic limit (PL), and liquid limit (LL) of a given soil. The Plasticity Index (PI), commonly used to characterize cohesive soils (i.e., as a clay or silt), is a measure of the range of water content over which the soil remains plastic and is given as PI = LL – PL. The PI ranges from 10 to 20 for most silts and from 20 to 40 for many clays, although highly plastic clays may have a PI upward of 80. See Figure C.1.

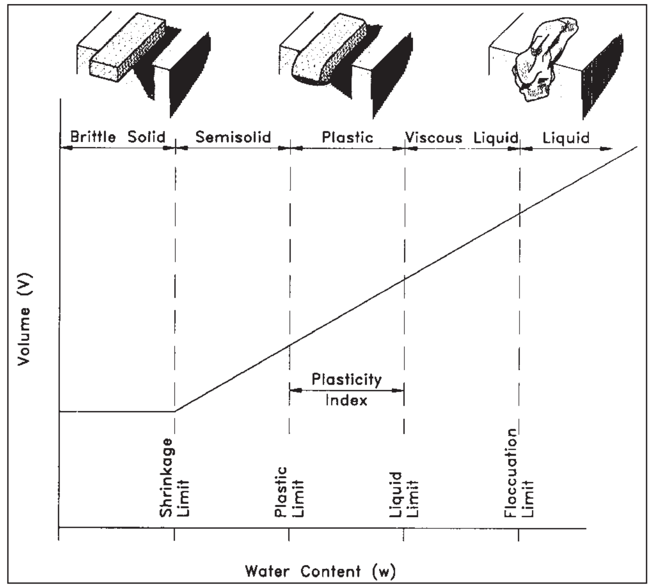

FIGURE C.1 Atterberg limits—phase diagram.

Cohesionless soils (i.e., sands and gravels): Coarse-grained soils most effectively characterized by particle-size distribution.

Cohesive soils (i.e., clays): Fine-grained soils whose behavior (and engineering properties) ranges greatly

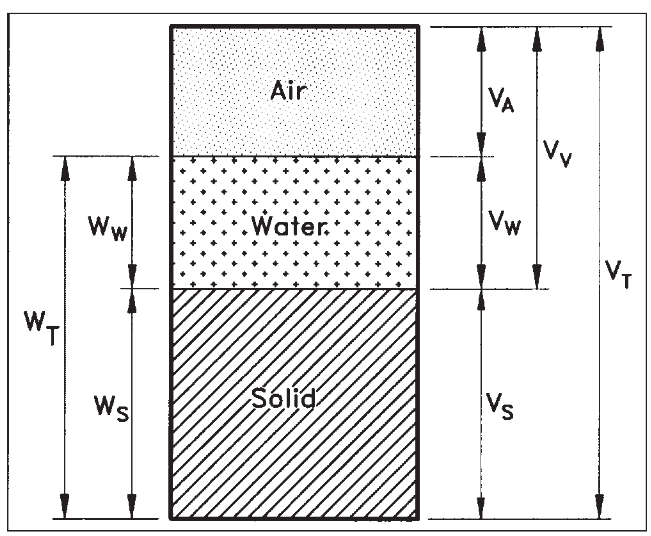

FIGURE C.2 Three-phase schematic of soil sample.

TABLE C.1 Volume Relationships

Property	Definition	$S = 100\%$	$S < 100\%$				
V_s	Vol. of solids		$\frac{W_s}{G_s\gamma_w}$	$V_T - (V_a + V_w)$	$V_T(1 - n)$	$\frac{V_T}{1 + e}$	$\frac{V_v}{e}$
V_w	Vol. of water		$\frac{W_w}{\gamma_w}$	$V_v - V_a$	SV_v	$\frac{SV_Te}{1 + e}$	SV_se
V_a	Vol. of air	0	$V_T - (V_s + V_w)$	$V_v - V_w$	$(1 - S)V_v$	$\frac{(1 - S)V_Te}{1 + e}$	$(1 - S)V_se$
V_v	Vol. of voids	$\frac{W_w}{\gamma_w}$	$V_T - \frac{W_s}{G_s\gamma_w}$	$V_T - V_s$	$\frac{V_sn}{1 - n}$	$\frac{V_Te}{1 + e}$	V_se
V_T	Total volume	$V_s + V_w$		$V_s + V_a + V_w$	$\frac{V_s}{1 - n}$	$V_s(1 + e)$	$\frac{V_v(1 + e)}{e}$
n	Porosity		$\frac{V_v}{V_T}$	$1 - \frac{V_s}{V_T}$	$1 - \frac{W_s}{G_sV_T\gamma_w}$	$\frac{e}{1 + e}$	
e	Void ratio		$\frac{V_v}{V_s}$	$\frac{V_T}{V_s} - 1$	$\frac{n}{1 - n}$	$\frac{W_wG_s}{W_sS}$	$\frac{G_sV_T\gamma_w}{W_s} - 1$

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from solid to liquid based on moisture content; thus, cohesive soils are best characterized by properties related to plasticity.

Density: The weight of a given amount of soil for a specific volume (typically expressed as pounds per cubic foot), often expressed as wet unit weight or dry unit weight. Density or unit weight also can be expressed as in situ (in-place) density or as a specific soil target density based on a reference standardized compaction of soil performed in a laboratory (standard Proctor test, ASTM D-698 and modified Proctor test ASTM D-1557).

Gradation: Used to determine particle size and classification of soil. Soil gradation is typically specified for controlled backfill material, dam embankments, and soil filters to prevent piping), as well as subbase for roads and foundations. Gradation is determined by the relative amounts (by dry weight) of individual particle sizes in a sample. Two standard test methods exist for gradation analysis: sieve analysis (ASTM D-422), shown in Figure C.3, and hydrometer analysis (ASTM D-1140). Particle-size distribution curves for three different soil samples subjected to a standard sieve analysis are shown in Figure C.4. Terms associated with soil

TABLE C.2 Weight Relationships

Property	Definition	$S = 100\%$	$S < 100\%$		
W_s weight of solids	Measured	$\frac{W_T}{(1 + W)}$	$GV\rho_w(1 - n)$	$\frac{W_wG}{eS}$	
W_w weight of water	Measured	wW_s	$S\rho_wV_v$	$\frac{eW_sS}{G}$	$V \cdot \rho_D \cdot W$
W_T total weight of sample	$W_s + W_w$	$W_s(1 + W)$			

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TABLE C.3 Unit Volume Relationships

Property	Definition	$S = 100\%$	$S < 100\%$				
γ_{Dry}	Dry unit wt.	$\frac{W_s}{V_s + V_w}$	$\frac{W_s}{V_T}$	$\frac{W_T}{V(1+w)}$	$G_s\gamma_w(1-n)$	$\frac{G_s\gamma_w}{1+e}$	$\frac{G_s\gamma_w}{1+\frac{wG_s}{S}}$
γ_{wet}	Wet unit wt.	$\frac{W_s + W_w}{V_s + V_w}$	$\frac{W_s + W_w}{V_T}$	$\gamma_D(1+w)$	$G_s\gamma_w(1-n) * (1+w)$	$\frac{(G_s + Se)\gamma_w}{1+e}$	$\frac{(1+w)\gamma_w}{\frac{w}{S}+\frac{1}{G}}$
γ_{sat}	Saturated unit wt.	$\frac{W_s + W_w}{V_s + V_w}$	$\frac{W_s + V_v\gamma_w}{V_T}$	$\frac{W_s}{V} + \frac{\gamma_w e}{1+e}$	$\frac{(G_s + e)\gamma_w}{1+e}$	$\frac{(1+w)\gamma_w}{w+\frac{1}{G_s}}$	

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gradations used to identify soil properties further include:

- Effective size—grain diameter at 10 percent finer (D_{10})
- Uniformity coefficient (C_u) is an indicator of the shape of the particle size distribution curve. Given as:

$$C_u = D_{60}/D_{10} \tag{C.1}$$

where $C_u < 2$ is a poorly graded or uniform soil and $C_u > 4$ is a well-graded soil.

- Coefficient of gradation (C_c)

$$C_c = D_{30}^2/(D_{60} \times D_{10}) \tag{C.2}$$

Phase diagram: Tool used to define weight-volume relationships among the three phases that constitute soils. From the specific quantities measured in a phase diagram, inferences about the soil's physical and engineering properties (including such things as the unit weight, specific gravity, porosity, void ratio, shear strength, loading and deformation behavior, permeability, consolidation, and shrink-swell behavior) can be made. The phase diagram and the inherent weight-volume relationships are summarized in Figure C.2 and Tables C.1, C.2, C.3, and C.4.

Soil: Organic and inorganic material of the earth's surface that exists as a mixture of three distinct phases—water, air (gasses), and solids.

Permeability

The study of geotechnical engineering requires a thorough understanding of the sometimes complex integration of soil, water, and air. Variation in a soil's water content can dramatically alter its physical and strength characteristics. For instance, one can easily walk or even drive on wet sand and dry clay. But doing the same on wet clay and dry sand would prove very difficult (Liu, 1937).

Water flow through soil or any other porous material is dependent on an engineering property called *permeability.* Permeability is an important property of soil and influences the design and constructibility of nearly all land development projects. A few examples of common land development project components in which permeability should be considered are:

TABLE C.4 Additional Relationships

Property	Definition	$S = 100\%$	$S < 100\%$			
W	Moisture content	$\frac{n}{(1-n)G_s}$	$\frac{W_w}{W_s}$	$\frac{W_T}{W_s} - 1$	$\frac{Se}{G_s}$	$S\left(\frac{\gamma_w}{\gamma D} - \frac{1}{G_s}\right)$
S	Degree of saturation	1.00	$\frac{V_w}{V_v}$	$\frac{W_w}{V_v\gamma_w}$	$\frac{wG_s}{e}$	$\frac{w}{\frac{\gamma_w}{\gamma_D} - \frac{1}{G}}$
G_s	Specific gravity		$\frac{W_s}{V_s\gamma_w}$	$\frac{Se}{w}$		

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USA Sieve Series (ASTM Specification E-11-70) Showing the Corresponding Soil Grain Size (ASTM D-2487)

Standard[B]	Alternative	Description	Standard	Alternative	Description
125 mm	5		2.00 mm	No. 10	
106 mm	4.24	Cobbles*	1.70 mm	No. 12	
100 mm[D]	4		1.40 mm	No. 14	
90 mm	3 ½		1.18 mm	No. 16	Medium
75 mm	3		1.00 mm	No. 18	Sand
63 mm	2 ½		850 μm[F]	No. 20	
53 mm	2.12		710 μm	No. 25	
50 mm[D]	2		600 μm	No. 30	
45 mm	1 ¾	Coarse	500 μm	No. 35	
37.5 mm	1 ½	gravel	425 μm	No. 40	
31.5 mm	1 ¼		355 μm	No. 45	
26.5 mm	1 .06		300 μm	No. 50	
25 mm[D]	1		250 μm	No. 60	
22.4 mm	7/8		212 μm	No. 70	Fine Sand
19 mm	¾		180 μm	No. 80	
16 mm	5/8		150 μm	No. 100	
13.2 mm	.530		125 μm	No. 120	
12.5 mm[D]	½		106 μm	No. 140	
11.2 mm	7/16	Fine gravel	90 μm	No. 170	
9.5 mm	3/8		75 μm	No. 200	
8.0 mm	5/16		63 μm	No. 230	
6.7 mm	0.265		53 μm	No. 270	Fines
6.3 mm[D]	¼		45 μm	No. 325	
5.6 mm	No. 3 ½		38 μm	No. 400	
4.75 mm	No. 4		32 μm	No. 450	
4.0 mm	No. 5		25 μm[D]	No. 500	
3.35 mm	No. 6	Coarse Sand	20 μm	No. 635	
2.80 mm	No. 7				
2.36 mm	No. 8				

[B] These standard designations correspond to the values for test sieve apertures recommended by International Standards Organization, Geneva, Switzerland.

* Cobbles range from 300 mm to 9 mm; particles greater than 300 mm are designated as boulders.

[D] These sieves are not in the standard series but they have been included because they are in common usage.

[E] These numbers 93½ to 635 are the approximate number of openings per linear inch, but it is preferred that the sieve be identified by the standard designation in millimeters or micrometers.

[F] 1000 μ-1 mm.

FIGURE C.3 Sieve analysis. Copyright ASTM. Reprinted with permission.

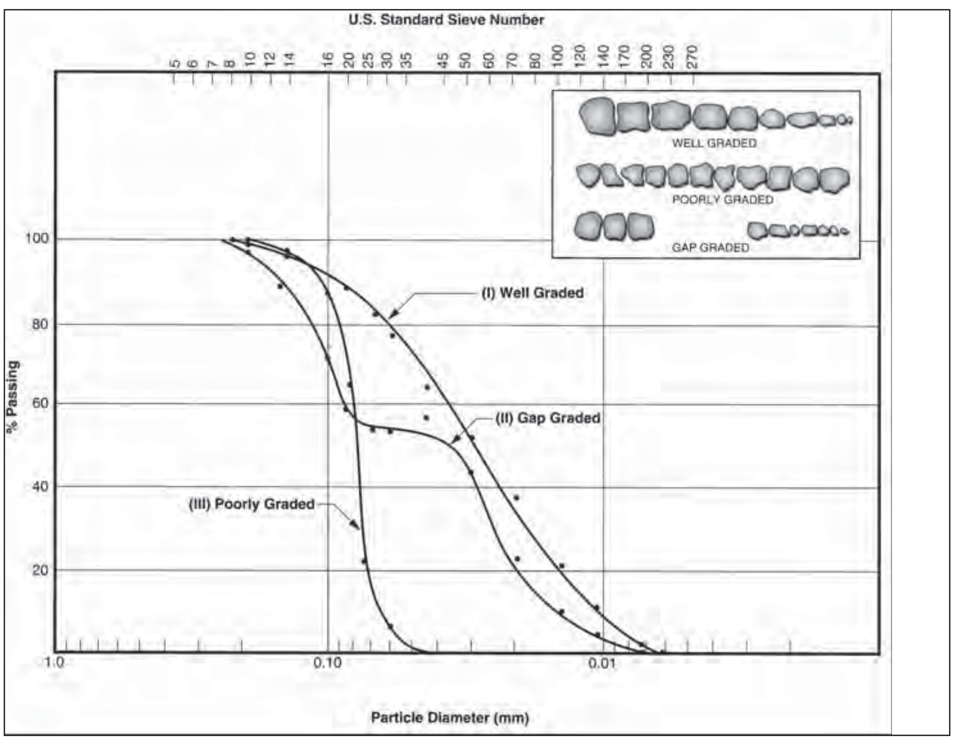


FIGURE C.4 Particle-size distribution curves.

- Seepage of water through dams and levees
- Water well recharge times and dewatering of excavations
- Foundation design—rate of settlement of fine-grained soils
- Roadway subgrade and drainage design
- Stormwater management facility design, particularly if implementing low-impact development techniques, which often rely on infiltration
- Drainage, capillary action, and frost action

Because soils are often deposited in relatively horizontal layers, vertical and lateral permeability of soils varies widely even in the most homogeneous soil deposits. Nonhomogeneous layering in soil deposits increases this natural variability. For engineering purposes, the permeability of a soil is based on Darcy's law and is discussed in terms of the *constant of proportionality* κ, also known as the *coefficient of permeability,* and has the units of velocity. The determination of a soil's coefficient of permeability κ is made in one of several ways. Approximate values can be obtained from laboratory testing using the constant head (ASTM D-2434) or falling head permeability test. Table C.5 provides some information on the range of the coefficient of permeability, drainage characteristics, and applicable testing methods for determining κ values for common soil classes.

Field pump testing utilizing an extraction well in concert with a series of radial spaced observation wells can be used for large-scale dewatering design. Single well tests, such as "slug" testing, can also be used to estimate permeability. Finally, there are some empirical formulas that can be used to obtain rough orders of magnitude of the coefficient of permeability.

For clean cohesionless soils, Hazen (1911) proposed:

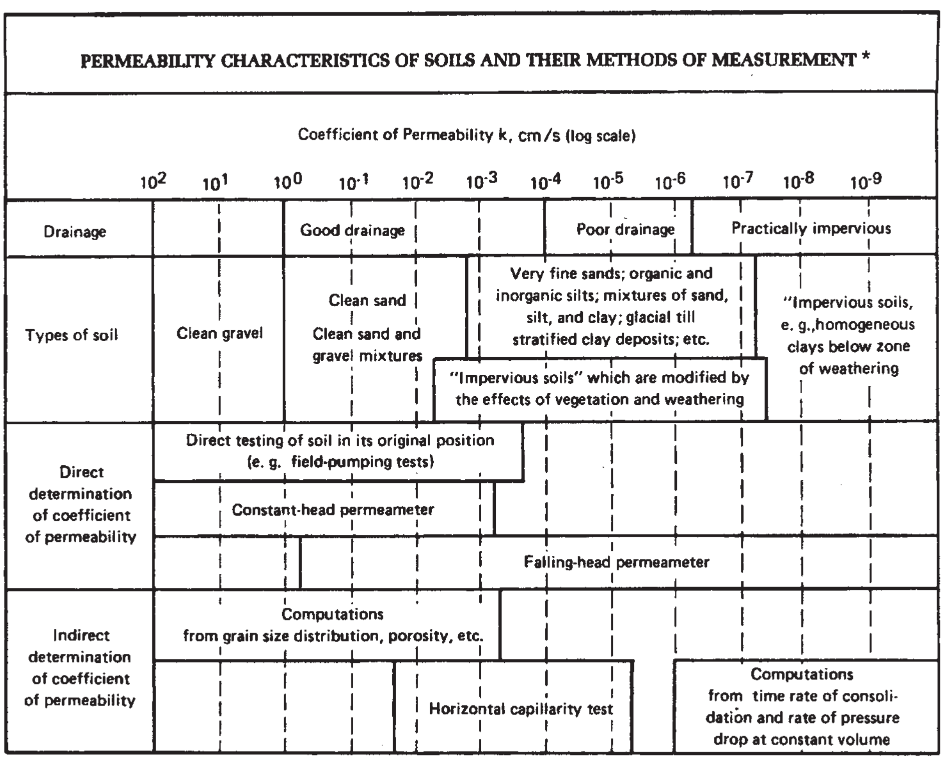
$$\kappa = C(D_{10})^2 \qquad \text{(C.3)}$$

where κ = coefficient of permeability in mm/sec, D_{10} = effective grain size in mm, and C = a constant ranging from 10 to 15.

Shear Strength

The stability of a soil is largely dependent on its shearing strength, which is a measure of the resistance to sliding between soil particles. Internal friction and cohesion are the two components that combine to produce the shearing resistance. True cohesion is the magnetic-like attraction between particles due to the molecular structure of the individual particles. Many partially saturated soils, including clays, silts, and even sands, also have apparent cohesion brought about by capillary action of the soil moisture binding the soil particles together. This apparent cohesion is lost when the soil becomes saturated or loses all or most of its moisture. True cohesion is inherent in all clays as well as some other fine-grained soils. Friction is the resistance of the particles rubbing across one another. Frictional resistance depends on the physical charac-

TABLE C.5 Permeability Characteristics of Soils



*After Casasrande and Fadum (1940), from Hunt (1984).

teristics of the soil grains, such as particle angularity, surface roughness, sphericity, gradation, and relative density. The measure of this resistance is referred to as the *angle of internal friction* ϕ. The direct-shear test (ASTM D-3080) is especially useful for determining the angle of internal friction ϕ for compacted backfill soils adjacent to retaining walls.

The voids between soil particles are called *pore spaces*. The water and the corresponding pressure are referred to as pore water and pore pressure. Water flowing through the soil skeleton, although usually very slow, affects the transmission of the resisting forces among the soil particles, thus influencing the compression and shear resistance of the soil. Within the context of soil strength, two commonly used terms are *drained* and *undrained shear strength*. The drained strength is the tested strength of a saturated soil sample as the water is allowed to dissipate out of the soil while the loading is applied. This strength parameter is applicable for use when the underlying soils are granular (i.e., pervious). Hence, as the surface load (e.g., shallow footing) is applied to an upper saturated soil layer, the water in the soil would permeate into the granular soil. However, if the lower soil layers are impermeable or have very low permeability, the undrained strength parameter is used in the design analysis.

The shearing strength of a soil is given by the Coulomb equation:

$$s = c + \sigma \tan \phi \tag{C.4}$$

where s = shearing strength, c = cohesion, σ = normal stress on the shear plane, and ϕ = angle of internal friction.

Shearing strength of a soil is a combination of the cohesive properties and the friction properties. Figure C.5 illustrates this relationship for both cohesionless (c = 0 and ϕ = constant, therefore s is proportional to σ) and cohesive (ϕ = 0, therefore s is entirely dependent on c) soils.

Common land development applications where shear strength is a design consideration include:

- Outfall stability, particularly when assessing natural channels
- Slope stability when determining acceptable grading schemes
- Erosion and sediment control analysis
- Cohesive soils within the foundation area

Compressibility

Nearly everyone has seen pictures of the Leaning Tower of Pisa, listing to one side and looking like it could topple at any second. Settlement has plagued the designers and builders of this famous structure for more than 700 years. Countless other structures and civil projects have suffered a similar or more catastrophic fate (Sowers, 1979).

Structures built on soil are subject to settlement. Most often settlement results from increased stress, which causes compressive deformation (i.e., a reduction in the soils void ratio) in the supporting soil matrix due to the weight of the new structures. Other causes of settlement include dynamic forces, changes in the ground water table elevation, and nearby excavations (Liu, 1937).

Settlement generally takes the form of relatively immediate subsidence and then, in some soils, a longer-term, time-dependent subsidence. Compression (consolidation) is the result of soil particles rearranging themselves into a tighter, more compact state. For dry soils, which are made up of soil particles and air voids (a two-phase system), settlement typically occurs quite rapidly under the application of an increased load. The air voids are easily compressed as the soil grains continue to slide past each other, until equilibrium is achieved between the increased stress and the resisting friction generated from adjacent soil grains. This type of settlement behavior is referred to as *immediate* or *distortion settlement* S_d.

Soils, which are characterized by a three-phase system composed of soil, air voids, and water (or when a soil matrix is 100 percent saturated), undergo a time-dependent consolidation, since the applied load is initially carried by the soil and water. With the passing of time, the water is squeezed out of the soil, allowing the grains to move closer together.

The rate at which the water is displaced is governed by the soil's permeability. Soils with high permeability (i.e., course-grained soils) require relatively short time periods to consolidate, and most of the settlement is complete by the time construction operations are completed (Liu, 1937).

Soils of low permeability (i.e., fine-grained clay soils) can

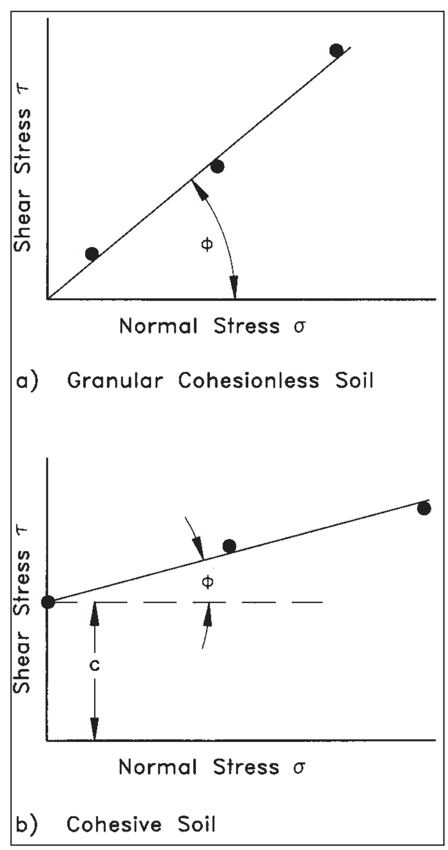


Figure C.5 Shear strength for (*a*) granular soil and (*b*) cohesive soil.

experience consolidation settlements for many years and, in fact, may continue to be compressed well beyond the useful life of the structure; this is especially true of organic or peat soils. Note also that the rate of consolidation for a given soil is also related to the thickness of the soil layer, since that controls the distance the pore water has to travel to escape the soil layer.

Settlement associated with the displacement of pore water out of a soil layer is referred to as *primary consolidation settlement* S_c. Following the primary consolidation, additional consolidation settlement may occur, although it will be at a reduced rate and magnitude. This additional, often-negligible settlement is known as *secondary compression* S_s and results from the reorientation and breaking of the clay-to-clay bonds. Secondary compression is also referred to as soil *creep*.

The total settlement S to be anticipated is obtained by summing the aforementioned settlement components and is represented by the following formula (Winterkorn, 1975).

$$S = S_d + S_c + S_s \qquad \text{(C.5)}$$

where S = total settlement, S_d = distortion settlement, S_c = primary consolidation settlement, and S_s = secondary compression settlement

A few examples of common land development project components in which soil compressibility should be a primary design consideration are:

- When structural loads are large
- When developing within known deposits of clays and silts
- When developing over recently deposited soils, which may be settling under their own weight
- Where large deposits of engineered fill are required to reach finished grade

Another type of settlement that can occur is differential settlement. Differential settlement occurs when one part of the structure moves, or settles, relative to another part, with the difference referred to as *differential settlement*. A common example of differential settlement occurs when a portion of a building is founded on rock, while the other side is founded on compacted (engineered) fill soils. When the building load is applied to the foundations, the softer fill soils compress, whereas the stronger rock foundation compresses very little, resulting in uneven settlement across the structure. This often results in structural distress and/or cracking. See Figure C.6.

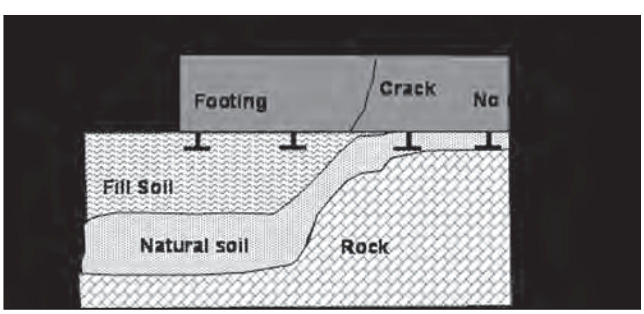


FIGURE C.6 Illustrative of differential settlement.

SOIL CLASSIFICATION

Soil classification is a means to describe soil characteristics according to the interests of a particular discipline. From an engineering perspective, although a soil is nonhomogeneous and anisotropic (reacts differently under different forces), there are methods available to systematically categorize soils for construction purposes. Although soil classification provides a description for evaluating how the soil will likely behave based on its engineering properties, this alone cannot be the sole criterion for measuring the soils' behavior. A detailed investigation of the soil, using subsurface exploration methods and other detailed soil investigations and laboratory tests, as appropriate, is needed to supplement the predicted behavior based on generalized classification. Specific laboratory and field tests provide reasonable assurance of the anticipated performance of the soil as a construction medium. There are several standardized soil classification methodologies commonly in use today, including the Unified Soil Classification (USC) system, the American Association of State Highway and Transportation Officials (AASHTO) System for roads, the Natural Resource Conservation Service system, and others (see comparisons in Table C.6). Geotechnical engineers typically use the USC classification in describing soils for land development purposes.

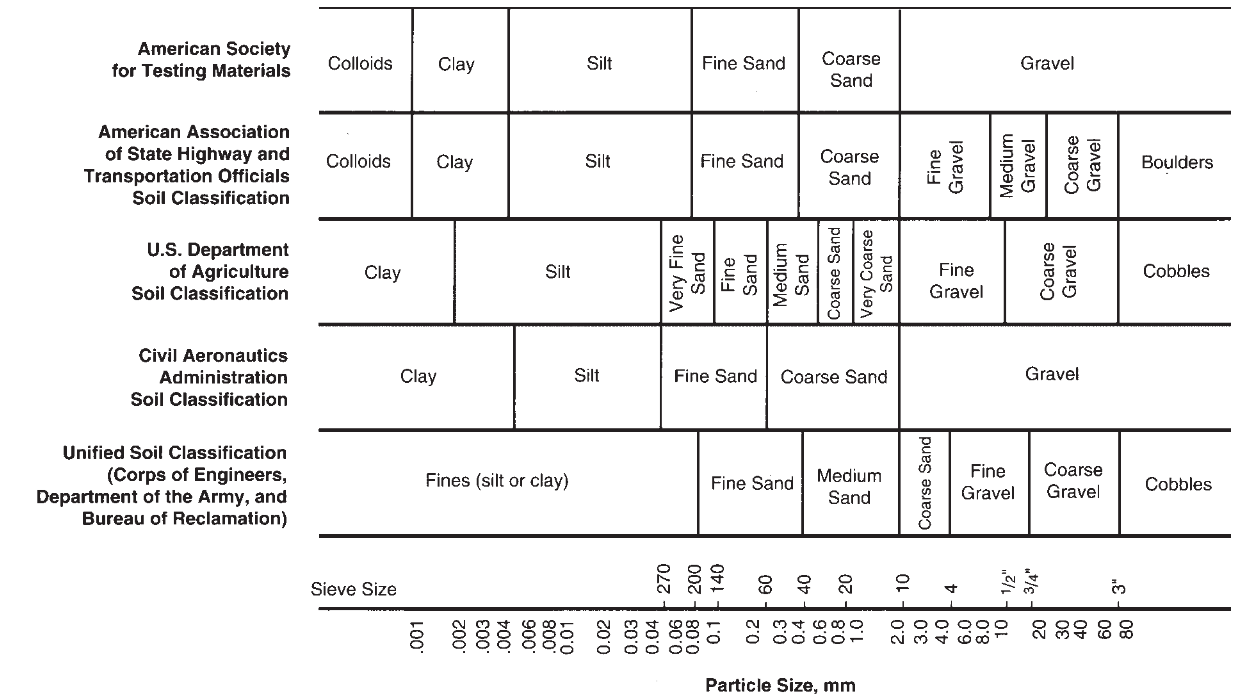
Unified Soil Classification System (ASTM D-2487)

Typical soils that are encountered during land development are a mixture of gravels, sands, clays, and silts. Other earth materials are bedrock, weathered rock, boulders, loam, organics, loess, and topsoil. ASTM D-2487, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), groups soil into two broad categories: coarse-grained soils and fine-grained soils. The letters G, S, C, and M designate textural categories of gravel, sand, clay, and silt, respectively. Additionally, this system uses W and P to indicate a well-graded or poorly graded soil, and H to indicate high or L for low plasticity. The underlying assumption for the USC system is that the engineering properties of any coarse-grained soil depend on the particle-size distribution. For fine-grained soils, the engineering properties are determined by the soil's plasticity. See Figure C.7.

To determine the classification using the USC system, a sieve and/or hydrometer analysis test is run and the results are compared to the appropriate flow chart. First, the soil is classified as to whether it is a coarse-grained soil or fine-grained soil. This is based on the weight fraction larger or smaller than the No. 200 sieve (0.075 mm).

Coarse-grained soils are those that have 50 percent or more of the soil sample larger than 0.075 mm (No. 200 sieve). As shown in the flowchart of Figure C.8, coarse-grained soils are divided into either sands or gravels. If more than 50 percent of the coarse fraction is larger than 4.75 mm (No. 4 sieve), the sample is a gravel. For a sample with more than 50 percent of the coarse fraction smaller than the No. 4 sieve, the soil is a sand. The symbols G and S identify

TABLE C.6 Particle-Size Limits for Selected Agencies



(Reprinted with permission from Fang, Hsai-Yang, ed. 1991. *Foundation Engineering Handbook,* 2nd ed., New York: Van Nostrand Reinhold.)

the soil as a gravel or sand. Gravels and sands are further classified according to gradation, including the amount and type of fines[1] in the sample. If the amount of fines is less than 12 percent, the uniformity coefficient C_u and gradation coefficient C_c are used to further classify the soil. For a sample with the amount of fines greater than 12 percent, the plasticity chart in Figure C.7 is used to further classify the sample.

[1]Fines are soil particles smaller than 0.075 mm (No. 200 sieve).

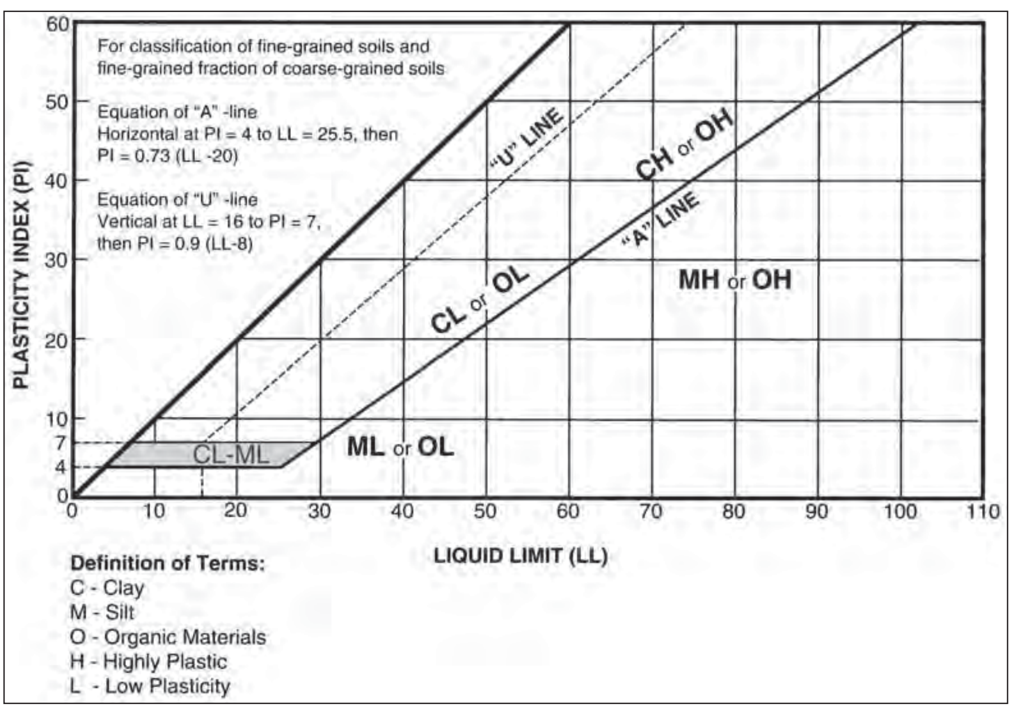


FIGURE C.7 Plastic chart. (Copyright ASTM. Reprinted with permission)

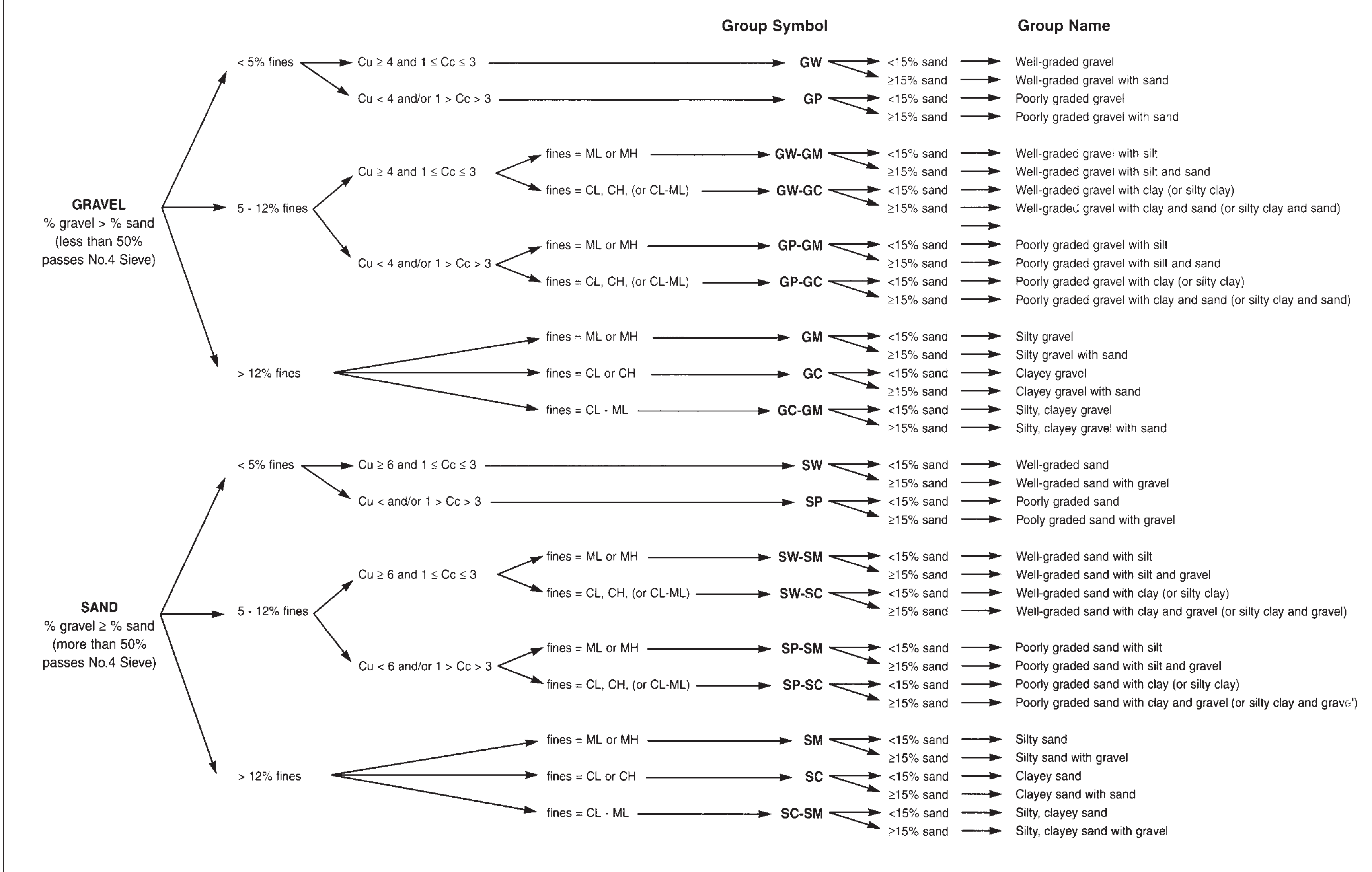


FIGURE C.8 USC Flowchart for classifying coarse-grained soil. (Copyright ASTM. Reprinted with permission)

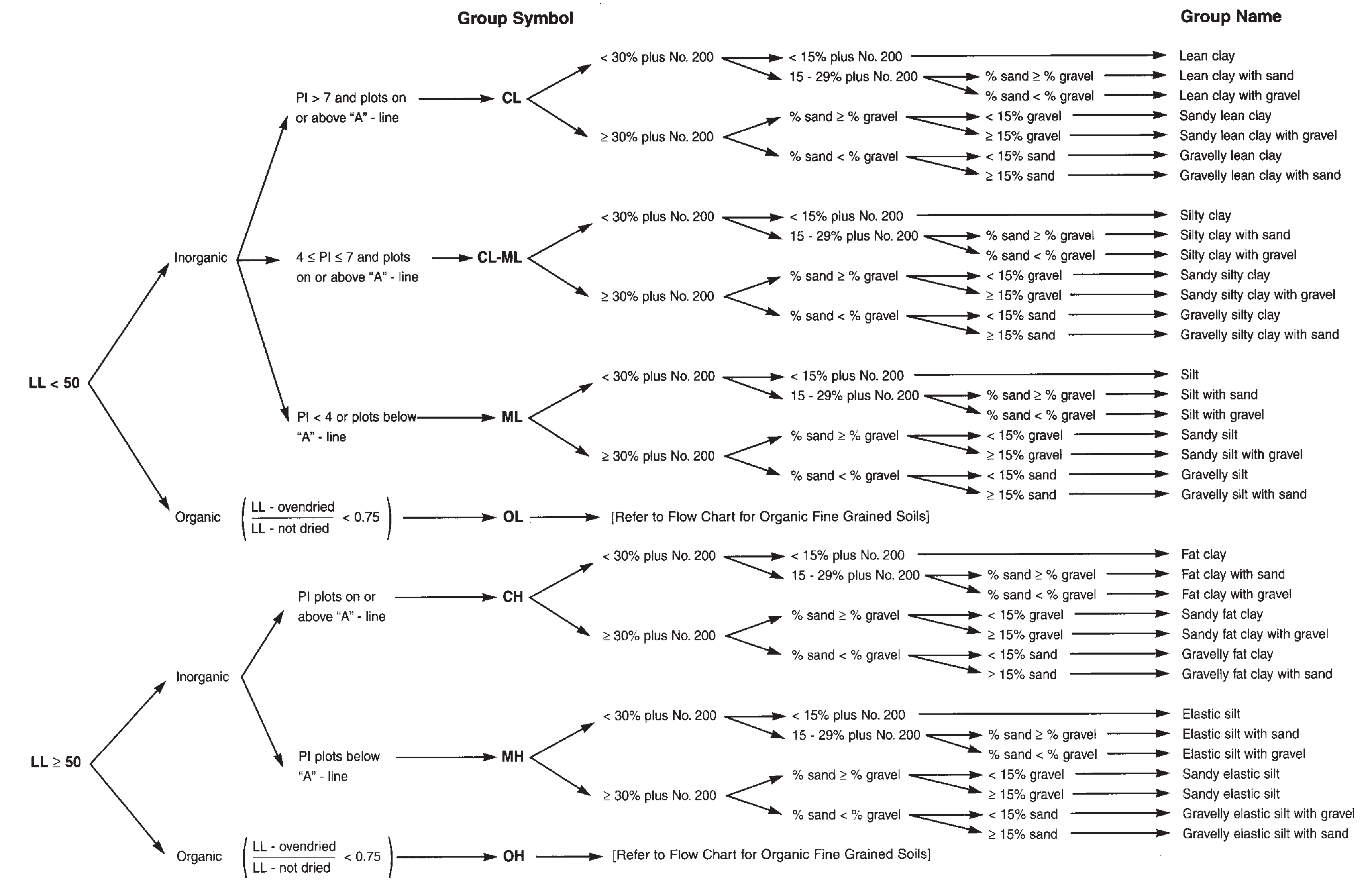


FIGURE C.9 USC Flowchart for fine-grained soils. (Copyright ASTM. Reprinted with permission)

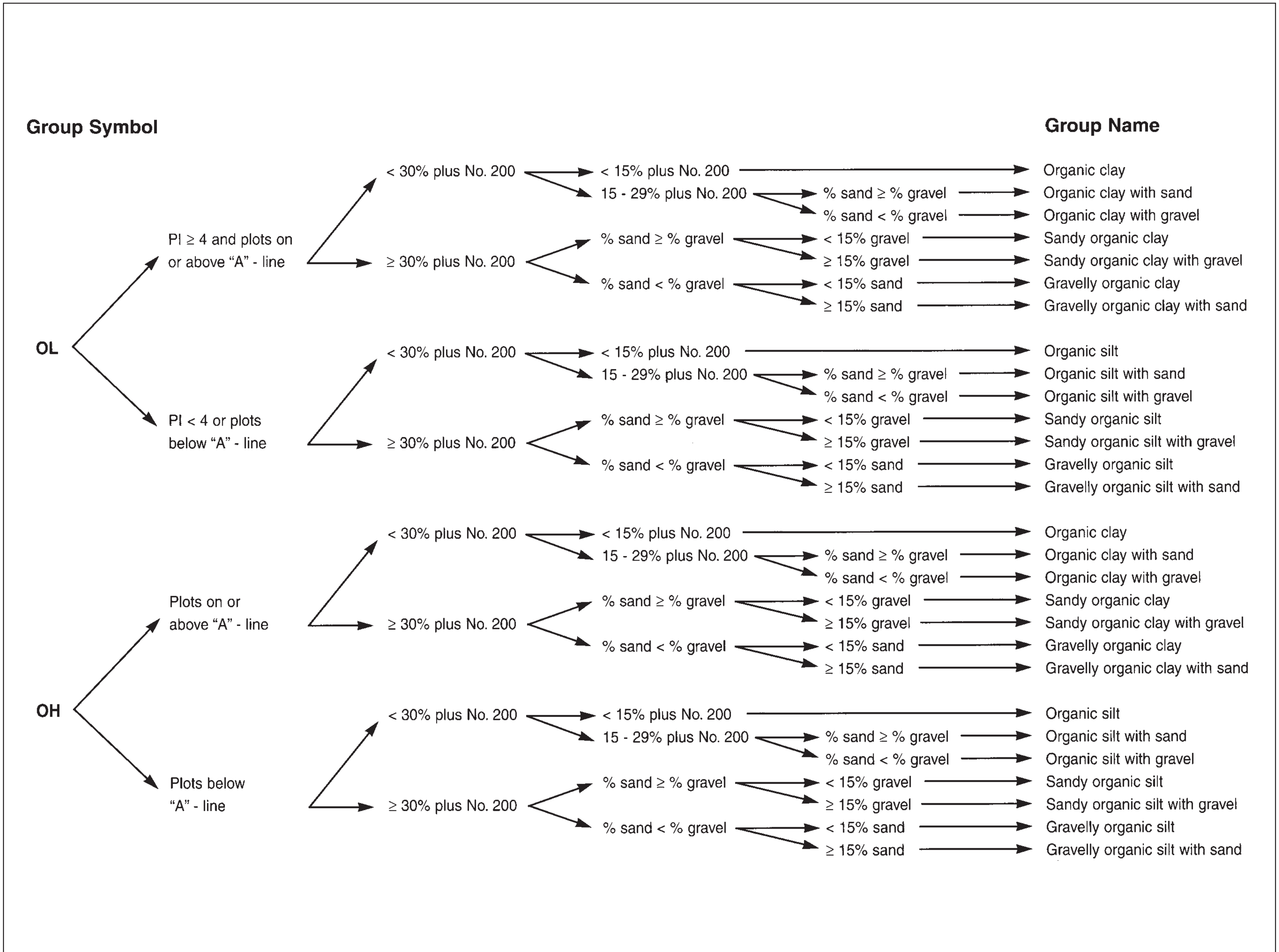


FIGURE C.10 USC Flowchart for organic fine-grained soils. (Copyright ASTM. Reprinted with permission)

TABLE C.7 Engineering Uses for USC Soils

		Important Properties				Relative Desirability for Various Uses*									
						Rolled Earth Dams			Canal Sections		Foundations		Roadways		
													Fills		
Typical Names of Soil Groups	Group Symbols	Permeability when Compacted	Shearing Strength when Compacted and Saturated	Compressibility when Compacted and Saturated	Workability as a Construction Material	Homogeneous Embankment	Core	Shell	Erosion Resistance	Compacted Earth Lining	Seepage Important	Seepage not Important	Frost Heave not Possible	Frost Heave Possible	Surfacing
Well-graded gravels, gravel-sand mixtures, little or no fines	GW	Pervious	Excellent	Negligible	Excellent	—	—	1	1	—	—	1	1	1	3
Poorly graded gravels, gravel-sand mixtures, little or no fines	GP	Very pervious	Good	Negligible	Good	—	—	2	2	—	—	3	3	3	—
Silty gravels, poorly graded gravel-sand-silt mixtures	GM	Semipervious to impervious	Good	Negligible	Good	2	4	—	4	4	1	4	4	9	5
Clayey gravels, poorly graded gravel-sand-clay mixtures	GC	Impervious	Good to fair	Very low	Good	1	1	—	3	1	2	6	5	5	1
Well-graded sands, gravelly sands, little or no fines	SW	Pervious	Excellent	Negligible	Excellent	—	—	3 if gravelly	6	—	—	2	2	2	4
Poorly graded sands, gravelly sands, little or no fines	SP	Pervious	Good	Very low	Fair	—	—	4 if gravelly	7 if gravelly	—	—	5	6	4	—
Silty sands, poorly graded sand-silt mixtures	SM	Semipervious to impervious	Good	Low	Fair	4	5	—	8 if gravelly	5 erosion critical	3	7	8	10	6
Clayey sands, poorly graded sand-clay mixtures	SC	Impervious	Good to fair	Low	Good	3	2	—	5	2	4	8	7	6	2
Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity	ML	Semipervious to impervious	Fair	Medium	Fair	6	6	—	—	6 erosion critical	6	9	10	11	—
Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, slity clays, lean clays	CL	Impervious	Fair	Medium	Good to fair	5	3	—	9	3	8	10	9	7	7
Organic silts and organic silt-clays of low plasticity	OL	Semipervious to impervious	Poor	Medium	Fair	8	8	—	—	7 erosion critical	7	11	11	12	—
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	MH	Semipervious to impervious	Fair to poor	High	Poor	9	9	—	—	—	8	12	12	13	—
Inorganic clays of high plasticity, fat clays	CH	Impervious	Poor	High	Poor	7	7	—	10	8 volume change critical	9	13	13	8	—
Organic clays of medium to high plasticity	OH	Impervious	Poor	High	Poor	10	10	—	—	—	10	14	14	14	—
Peat and other highly organic soils	Pt	—	—	—	—	—	—	—	—	—	—	—	—	—	—

*No. 1 is most desirable, no. 14 is least desirable.

(Source: Lambe, T.W., and R.V. Whitman. *Soil Mechanics.* Copyright 1979. Reprinted by permission of John Wiley & Sons, Inc.)

The soil is classified as a fine-grained soil if 50 percent or more passes the No. 200 sieve. Figure C.9 is used to determine the fine-grained soil classification. These soils are classified as clays (C) or silts (M, from the Swedish word *mo,* for silt) according to the liquid limit and the plasticity index from Figure C.7. Organic, silty, and clayey soils are divided according to the liquid limit (LL). Those with high LL (i.e., >50) are CH or MH. A liquid limit less than 50 results in a soil designation as CL or ML (L indicates low plasticity). The flowchart for organic fine-grained soils (Figure C.10) is used if organics are predominant in the soil.

$$\text{(LL-oven dried)/(LL-not dried)} < 0.75 \tag{C.6}$$

Table C.7 provides general guidelines on the properties of soils classified by the USC system.

TYPES OF SOIL AND OTHER SUBSURFACE MATERIALS

Gravels and Sands

Gravels and sands are products of weathered rock. Gravel ranges from a maximum size of 3 inches (7.62 cm) to 0.2 inches (4.76 mm). Crushed stone, bank-run gravel, or pea gravel are just some of the names given to particular types of gravel, depending on origin and gradation. If the gravel is dense and composed of sound rock fragments, it can provide a good support for the building foundation. However, if the rock fragments are weak, loose, or very rounded, or overlie softer layers, they may not be suitable for foundations without ground improvement.

Sand materials are smaller than gravel, ranging from 0.074 to 4.76 mm by the USC system. Sand can be described in three sizes: fine from 0.074 to 0.42 mm, medium from 0.42 to 2 mm, and coarse from 2 to 4.76 mm. Both gravel and sand are described as cohesionless materials. Sands and gravels are also described in terms of relative density as very loose, medium dense, or very dense. Sands and gravels together can make excellent foundation materials if sufficiently dense or compact. However, loose or poorly compacted sands may yield excessive settlement. Depending on the situation, sands by themselves may not be suitable for foundations, embankments, and dams. Where subject to scour, the sand may erode beneath the foundation or from an embankment, resulting in failure of the structure. Caution is necessary when excavating in sands and gravels, as these materials are cohesionless and their slopes are not stable. Numerous utility trenches have failed, resulting in significant injury or death to construction workers. High ground water can particularly affect the stability of sandy subsoils during excavation, creating a running sand or a quick condition that causes rapid flow or collapse of the sand stratum.

Silts and Clays

Silts and clays are described as fine-grained soils; both will pass through a very fine sieve (200 openings per inch, also known as a No. 200 sieve). Both silts and clays are classified by particle size and plasticity. Plasticity and consistency are measured by ASTM D-423 (liquid limit) and D-424 (plastic limits). The liquid limit (LL) and plastic limit (PL) are boundary soil moisture contents wherein the soil begins to behave as a viscous liquid or a moldable plastic material, respectively. When the clay's moisture content is below the PL, the clay behaves like a brittle solid. When the moisture content is between the PL and the LL, the clay behaves like a moldable plastic material; when it is above the LL, the clay behaves like a viscous liquid. Silts and clays can perform satisfactorily or very poorly under foundation loads, depending on their moisture contents. Therefore, because of this sensitivity to moisture, when bearing foundations are planned on silts or clays, it is critical during construction to prevent these soils from becoming wet and absorbing too much moisture. Silts and clays are also described in terms of consistency as being very soft, soft, firm, stiff, very stiff, or hard. Silt particle size is barely perceptible to the human eye; it is smaller but still much coarser than clay. Clay is much finer than silt, and the primary method of determining the difference between clay and silt is conducted by timing settlement of the particles in a column of water (hydrometer) in the laboratory.

Bedrock

Bedrock is solid material composed of unweathered rock typically lying beneath surface deposits of soil such as sand, clay, or gravel. The three classes of rock based on geologic origin are igneous, sedimentary, and metamorphic. Igneous rocks are formed by solidification of molten material. They are generally uniform in structure and lack stratification and cleavage planes. Examples of igneous rock are granite, diorite, gabbro, basalt, and diabase.

Sedimentary rocks are products of weathering and disintegration of rock, then erosion and sedimentation, chiefly by water. These rocks are formed by mechanical cementation, chemical precipitation, and pressure. Examples of sedimentary rock are sandstone, limestone, dolomite, shale, and chert. Sedimentary rocks typically have rounded grains, stratifications, inclination of bedding planes, and abrupt color changes between layers.

Metamorphic rock is formed by the alteration of igneous or sedimentary rocks by heat and pressure. Typical metamorphic rock includes quartzite, marble, slate, gneiss, and schist. Some features include the ease with which parallel layers break into slabs. In general, harder and more sound rock is less susceptible to scour or crushing.

Usually natural bedrock is regarded as the best bearing material for structural foundations; however, there are conditions, such as sinkholes, close joints and fractures, weathering, and soil-filled seams, that can present problems. Bridge foundation failures have occurred due to scour of rock or rocklike materials. Building foundation failures have occurred due to sinkholes. Slope failures have occurred due to unfavorable orientation of clay-filled joints within an otherwise sound rock.

The ultimate bearing pressure of rocks can be taken conservatively as the average compression strength of unconfined rock core samples. Commonly, the core samples obtained during the subsurface investigation reveal that the rock across the site has imperfections and fractures that have a significant influence on rock behavior when external loads are applied. The spacing of discontinuities is an indication of overall rock quality. The allowable bearing pressure of rock varies depending on the quality of the rock and can be arrived at by applying a factor of safety to the ultimate bearing pressure appropriate to the quality of the rock. For example, for a good quality rock with widely spaced joints and fractures and no soil seams, the factor of safety may be as low as 2 or 3. For poor-quality rock with very close joints but no soil seams, the factor of safety may be 10 or more. Rocks with soil seams or open joints require special considerations.

Limestone

Limestone and dolomite contain substantial amounts of carbonate minerals (CO_3). Gypsum and anhydrite are salts composed of calcium sulfate ($CaSO_4$). All of these sedimentary minerals are highly soluble in water; consequently, the presence and development of subsurface cavities is a consideration, particularly where there is ground water movement through joints and fractures in the carbonate rock. Marl and chalk are other, similar types of materials typically found near shorelines.

The surface collapse of soil overlying a subsurface cavity is usually referred to as a *sinkhole,* particularly in limestone and dolomite terrain. Where sinkholes are abundant, the terrain is known as *karst topography.* Open-solution voids in the bedrock allow the erosion of overlying soil into the void by ground water movement. This action, in turn, forms a soil cavity at the bedrock surface, which will continue to enlarge in soil above the bedrock surface until the soil can no longer support itself and collapses, forming a sinkhole at the ground surface. These conditions emphasize the importance of positive surface and ground water control in karst regions. An example of surface collapse and preparation of the bedrock surface for remedial measures is shown in Figure C.11.

Sinkholes can occur where the rock below the land surface is limestone, carbonate rock, or salt beds. These rocks can be naturally dissolved by ground water circulating through them. This process can dissolve the rock, creating voids, spaces, and caverns underground. The overburden soil usually remains intact until the underground spaces grow too large and the surrounding rock weakens. If there is not enough support for the overburden above the spaces, then a sudden dramatic failure of the land surface can occur. These collapses can occur without warning and, in urban developed areas, can have significant consequences.

The most damage from sinkholes tends to occur in Florida, Texas, Alabama, Missouri, Kentucky, Tennessee, and Pennsylvania. See Figure C.12.

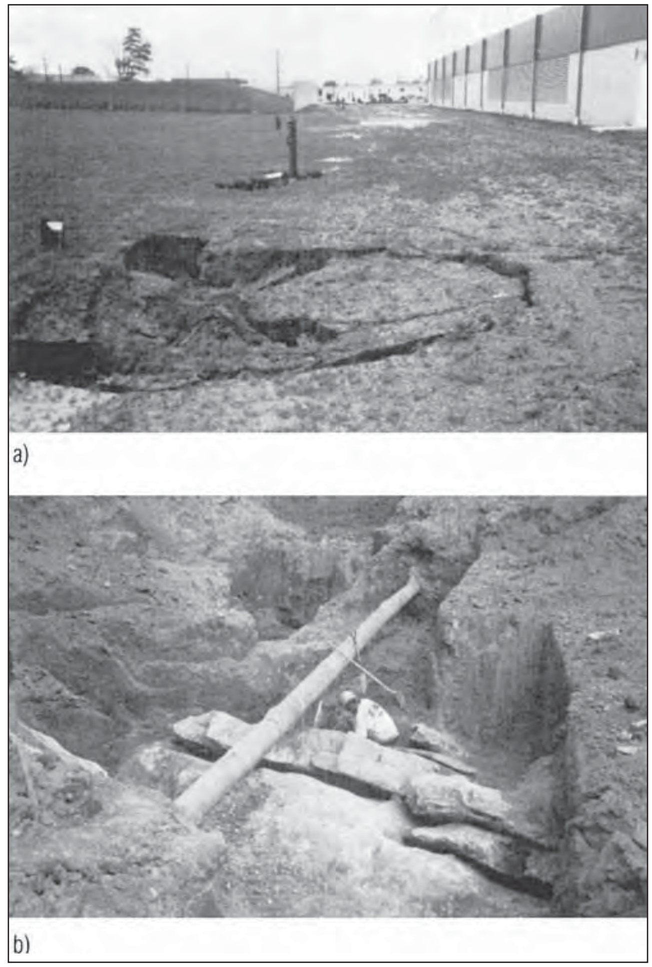


Figure C.11 (*a*) Surface collapse; (*b*) preparing bedrock for remedial measures.

Soil Types by Origin

Physical properties of some soils can be inferred from the mode of transportation displacing the soils and the geologic factors that influenced this formation. Table C.8 summarizes the geologic description of soils and their pertinent engineering characteristics.

Problem Soils

Certain types of soils require special attention because of their poor or irregular performance characteristics. The areal extent of such soils varies and specific problem soils are indigenous to selected areas of the country. The site may contain several isolated pockets of such soils or may be a major deposit area. Identification and location of problem soils early in the design process alleviates costly delays for redesign or unanticipated costs for additional excavation and reinforced foundation design. Additionally, provisions in local ordinances may require additional explorations, testing, and special designs. In extreme cases, the provisions may even preclude certain design elements of the project.

Expansive Clays. Certain clays undergo severe volume changes without any removal or application of external

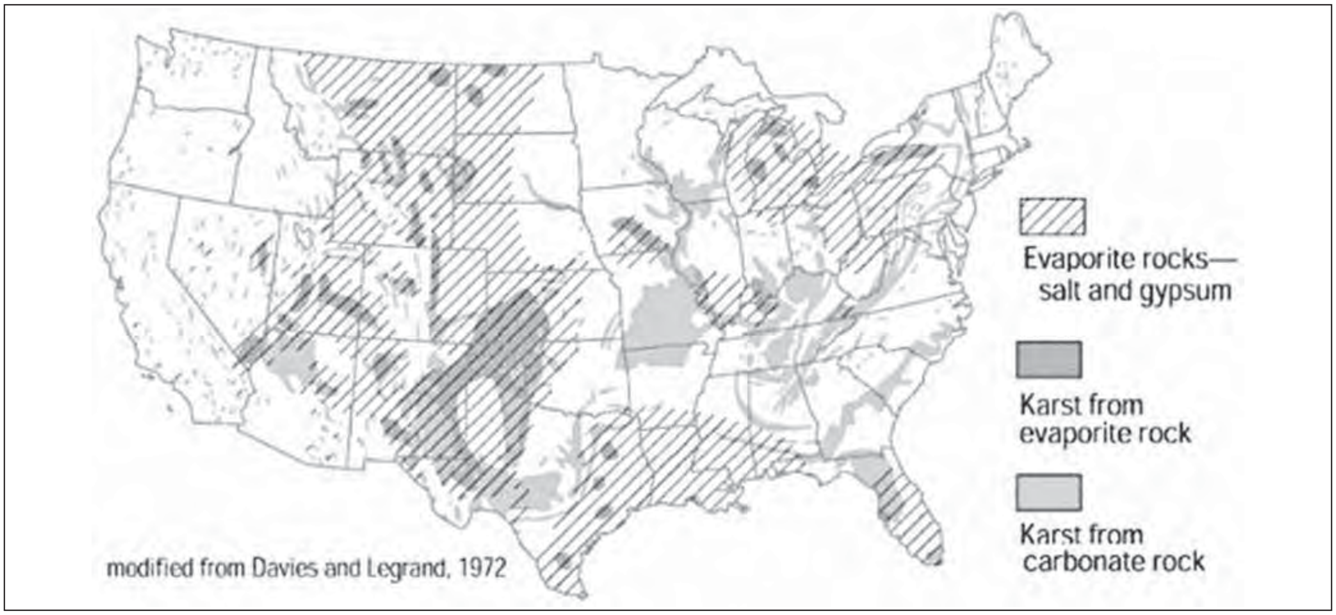


FIGURE C.12 Rock formation distribution in the United States.

loads. Such shrink and swell phenomena are the result of changing moisture conditions. Soils that are most susceptible to such moisture-induced volume changes are commonly included in problem soils categories. Typically, these soils have a high plasticity index (PI is the mathematical difference between liquid limit and plastic limit) and are predominant in the south and southwest United States. Local names for such soils are gumbo, adobe, black cotton, black jack, and others. Swelling of these soils can create high stresses on foundations, walls, and slabs, even to the extent of distressing and cracking basement walls and lifting light structures. Environmental factors greatly affect the behavior of expansive soils. Such factors as surrounding and underlying soils, hydrology, slope angle and length, and vegetation can influence the behavior of these expansive soils.

Damage to structures on expansive soils may not become evident for years after construction is completed. Shrinking of the soil during dry periods causes gaps to form under footings and foundations, thereby reducing the bearing support of the soil. This results in uneven structure settlement, causing cracks in the structure. When the soil becomes moist again, the expanding soil causes the foundation to rebound to near original position. After several cycles of shrink and swell, the structure does not return to its full original position; the building deteriorates further, and damage becomes apparent. Conversely, damage can be caused by excessive heave of the structure: if the foundation floor slabs are constructed on dry expansive clay, as during drought, the clay may later take on moisture during a wet period or as a result of leakage from a broken water or sewer line, resulting in significant swelling.

Buildings do not have to be directly situated on expansive soils to develop problems. Experience in Fairfax County, Virginia, shows that some houses have settlement problems with footings located on soils 3 feet above the expansive soil strata (see Figure C.13).

Using expansive soils as backfill around basement walls is not a recommended practice. Buildup of excessive pressures against the wall is caused after the soil settles and moisture is absorbed (see Figure C.14). During dry periods, additional soil particles fall into the cracks of the soil. When the soil expands again, the added soil, coupled with the volume increase, creates significant pressures on the wall. The high pressures and cyclic stress loads may eventually cause the wall to fail. Besides being a disruption and financial burden to the homeowner, the resulting wall movement can cause damage to sewer, gas, and water pipes, and precipitate secondary damages from those failures.

As illustrated in Figure C.15, large trees in expansive soils near buildings can exacerbate the damaging effects of shrink and swell phenomena. During a dry period, the tree's demand for water can cause localized shrinking of the soil. The decrease in volume in a small area coupled with increased volume elsewhere near the house creates a wavy, uneven ground surface around the structure. Large elm, poplar, and willow trees can contribute to such failure; however, small-diameter trees (less than 12 inches) and shallow roots result in significantly fewer failures. A recommendation is that trees be planted a distance of more than one-half their expected mature height away from the foundation.

When construction cannot be avoided on expansive soils, there are remedies that can mitigate damage potential, some of which can be costly. Such remedies include the following (Brown, 1988):

TABLE C.8 Summary of the Principal Geologic Soil Deposits

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Transported Soils *Alluvial*	Floodplain deposits. Deposits laid down by a stream within that portion of its valley subject to inundation by floodwaters.	
Material transported and deposited by running water.	Point bar. Alternating deposits of arcuate ridges and swales (lows) formed on the inside or convex bank of mitigating river bends. Ridge deposits consist primarily of silt and sand; swales are clay-filled.	Generally favorable foundation conditions; however, detailed investigations are necessary to locate discontinuities. Flow slides may be a problem along riverbanks. Soils are quite pervious.
	Channel fill. Deposits laid down in abandoned meander loops isolated when rivers shorten their courses. Composed primarily of clay; however, silty and sandy soils are found at the upstream and downstream ends.	Fine-grained soils are usually compressible. Portions may be very heterogeneous. Silty soils generally present favorable foundation conditions.
	Back swamp. The prolonged accumulation of floodwater sediments in flood basins bordering a river. Materials are generally clays but tend to become more silty near riverbank.	Relatively uniform in a horizontal direction. Clays are usually subject to seasonal volume changes.
	Alluvial terrace deposits. Relatively narrow, flat-surfaced, river-flanking remnants of floodplain deposits formed by entrenchment of rivers and associated processes.	Usually drained, oxidized. Generally favorable foundation conditions.
	Estuarine deposits. Mixed deposits of marine and alluvial origin laid down in widened channels at mouths of rivers and influenced by tides of body of water into which they are deposited.	Generally fine-grained and compressible. Many local variations in soil conditions.
	Alluvial-lacustrine deposits. Material deposited within lakes (other than those associated with glaciation) by waves, currents, and organochemical processes. Deposits consist of unstratified organic clay or clay in central portions of the lake or typically grade to stratified silts and sands in peripheral zones.	Usually very uniform in horizontal direction. Fine-grained soils generally compressible.
	Deltaic deposits. Deposits formed at the mouth of rivers, resulting in shoreline extension.	Generally fine-grained and compressible. Many local variations in soil condition.
	Piedmont deposits. Alluvial deposits at foot or hills or mountains. Extensive plains or alluvial fans.	Generally favorable foundation conditions.
Glacial Material transported and deposited by glaciers or by melting water from the glacier.	Glacial till. An accumulation of debris, deposited beneath at the side (lateral moraines) or at the lower limit of a glacier (terminal moraine). Material lowered to ground surface in an irregular sheet by melting glacier is known as a ground moraine.	Consists of material of all sizes in various proportions from boulders and gravel to clay. Deposits are unstratified. Generally present favorable foundation conditions, but rapid changes in conditions are common.
	Glacio-fluvial deposits. Coarse- and fine-grained material deposited by streams of meltwater from glaciers. Material deposited on ground surface beyond terminal of glacier is known as an outwash plain. Gravel ridges known as kames and eskers.	Many local variations. Generally present favorable foundation conditions.
	Glacio-lacustrine deposits. Material deposited within lakes by meltwater from glaciers. Consisting of clay in central portions of lake and alternate layers of silty clay or silt and clay (varved clay) in peripheral zones.	Very uniform in a horizontal direction.

TABLE C.8 *(Continued)*

Major Division	Principal Soil Deposits	Pertinent Engineering Characteristics
Marine Material transported and deposited by ocean waves and currents in shore and offshore areas.	Shore deposits. Deposits of sands and/or gravels formed by the transporting, destructive, and sorting action of waves on the shoreline.	Relatively uniform and of moderate to high density.
	Marine clays. Organic and inorganic deposits of fine-grained material.	Generally very uniform in composition. Compressible and usually very sensitive to remodeling.
Eolian Material transported and deposited by wind.	Loess. A calcareous, unstratified deposit of silts or sandy or clayey silt traversed by a network of tubes formed by root fibers now decayed.	Relatively uniform deposits characterized by ability to stand in vertical cuts. Collapsible structure. Deep weathering or saturation can modify characteristics.
	Dune sands. Mounds, ridges, and hills of uniform fine sand characteristically exhibiting rounded grains.	Very uniform grain size; may exist in relatively loose conditions.
Sedimentary Soils Residual Material formed by disintegration of underlying parent rock or partially indurated material.	Residual sands and fragments of gravel size formed by solution and leaching of cementing material, leaving more resident particles; commonly quartz.	Generally favorable foundation conditions.
	Residual clays formed by decomposition of silicate rocks, disintegration of shales, and solution of carbonates in limestone. With few exceptions, becomes more compact, rockier, and less weathered with increasing depth. At intermediate stage may reflect composition, structure, and stratification of parent rock.	Variable properties requiring detailed investigation. Deposits present favorable foundation conditions except in humid and tropical climates, where depth and rate of weathering are very great.
Organic	Peat. A somewhat fibrous aggregate of decayed and decaying vegetation matter having a dark color and odor of decay.	Very compressible. Entirely unsuitable for supporting building foundations.
Accumulation of highly organic material formed in place by the growth and subsequent decay of plant life.	Muck. Peat deposits that have advanced in decomposition to such extent that the botanical character is no longer evident.	
Colluvial Material transported and deposited by gravity.	Talus. Deposits created by gradual accumulation of unsorted rock fragments and debris at base of cliffs. Hillwash. Fine colluvium consisting of clayey sand, sand silt, or clay.	Previous movement indicates possible future difficulties. Generally unstable foundation conditions.
	Landslide deposits. Considerable masses of soil or rock that have slipped down, more or less as units, from their former position on steep slopes.	
Pyroclastic Material ejected from volcanoes and transported by gravity, wind, and air.	Ejecta. Loose deposits of volcanic ash, lapilli, bombs, etc.	Typically shardlike particles of silt size with larger volcanic debris. Weathering and redeposition produce highly plastic, compressible clay. Unusual and difficult foundation condition.
	Pumice. Frequently associated with lava flows and mud flows, or may be mixed with nonvolcanic sediments.	

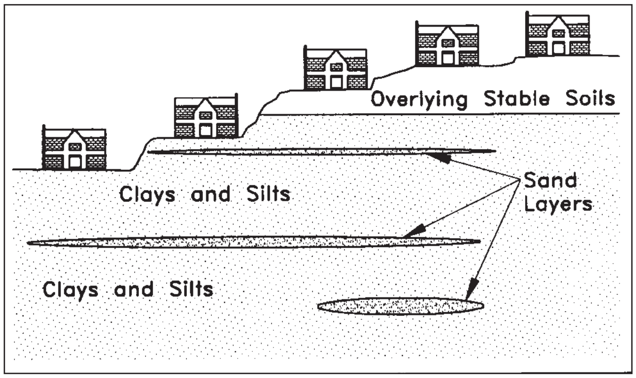


FIGURE C.13 Expansive soils underlying stable soil. (Reprinted with permission from Johnson, L.K. *Homeowners Guide to Overcoming Problems with Marine Clay.* Fairfax County, VA)

- Excavate expansive soils and replace with granular soil or other suitable material.
- Construct the foundation below the shrink-swell zone or near the water table (which then requires other special design considerations for the foundation).
- Design the foundation so that the dead loads totally counteract the heave.
- Use blankets of impervious soil adjacent to foundations and grade the areas away from the foundations to prevent surface water infiltration.
- Locate water and drainage lines to direct water around and away from foundations.

Frost-Susceptible Soils. Frost heave is a natural phenomenon and will occur wherever water in soil is exposed to sustained freezing temperatures. When the water in the voids freezes, it expands about 10 percent, which in itself does not create frost heave problems. Soil heaving due to freezing occurs when saturated fine-grained soils, within the capillary zone above the water table, form ice lenses, or layers parallel

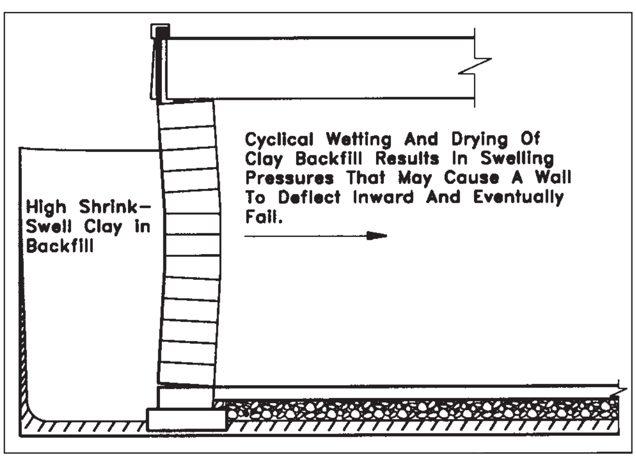


FIGURE C.14 Foundation wall damage from expansive soils. (Reprinted with permission from Johnson, L.K. *Homeowners Guide to Overcoming Problems with Marine Clay.* Fairfax County, VA)

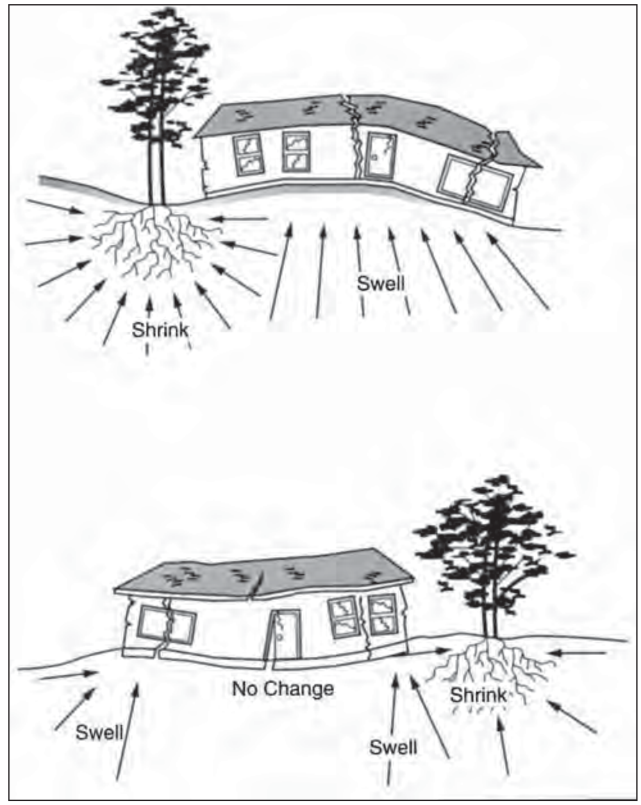


FIGURE C.15 Tree influence on expansive soils.

to the ground surface. Ground heaving increases as the ice lenses accumulate and grow to thicknesses of several inches.

Frost heave is particularly damaging to pavement and slabs due to the erratic distribution of the ice lenses, which results in differential heaving and cracking. Figure C.16 shows the damage caused by frost heave of a ground-level floor slab. Notice the deformed metal wall studs buckling from the upward displacement of the ground floor slab. The formation of ice lenses is illustrated in Figure C.17 (Sowers, 1979, p. 138).

Non-frost-susceptible soils are those that cannot readily support the capillary rise of water and therefore prevent the formation of ice lenses. These soils are typically free-draining soils like clean coarse sands, gravel, and crushed stone.

Typically, silty soils and very fine sands are prone to objectionable frost heave because they facilitate capillary rise. Frost-susceptible soils are typically nonuniform soils containing more than 3 percent particles finer than 0.02 mm and uniform soil if more than 10 percent is finer than 0.02 mm.

Prevention of frost heave in footings is most easily achieved by following the recommendations of the local building codes, for example, planning footings at depths below the local frost line. Controlling heave in slabs, walls, pavements, utilities, and other construction components can be achieved by removing frost-susceptible soils throughout the depth of frost penetration and replacing it with non-frost-susceptible soils. Alternatively, for pavements and

FIGURE C.16 Photo of frost heave damage to a concrete floor slab.

slabs, a horizontal blanket of coarse-grained free-draining sand, gravel, or crushed stone placed above the water level will break the capillary tension forces. Care should be taken when designing these blankets, as improper drainage or inadequate thickness could aggravate rather than prevent frost heave. (Sowers, 1979, p. 141). Figure C.18 shows common frost penetration depths in the United States. Frost penetration depth also affects most utility designs, specifically water, sewer, and storm. Minimum cover over these pipes is typically greater than or equal to the frost penetration depth, to prevent freezing of the conveyed fluids.

Metastable Soils. Collapsing soils are those that decrease in volume when they become saturated or when subjected to vibration after saturation. These are called metastable soils and are associated with fine sand-silt-clay materials deposited along the base of mountains and along alluvial fan deposits in arid and semiarid regions. Similar to expansive soils, collapsing soils are generally stable until the moisture content changes. Additional moisture disrupts the clay and water bonding that maintains the soil structure in its metastable condition, collapsing the soil into a more compact and stable condition, often resulting in rapid and severe settlement.

Loess, a soil found in sections of the midwestern and western United States, is the most common type of metastable soil. Compacted loess is a satisfactory foundation material for spread footings or mat foundations as long as the dry unit weight is around 99 lb/ft^3 or more. For shallow deposits (3 to 6 feet deep), compaction is necessary for the full depth of the deposit or above the permanent water table to ensure adequate performance. For loess with dry unit weights less than 99 lb/ft^3, pile foundations driven to underlying acceptable soil strata should be considered.

As previously mentioned, collapsing soils are typically found in desert arid and semiarid environments, alluvial valleys, and playas. Gypsum and anhydrite are often present in or around such soils. In general, these soils are very moisture sensitive and exhibit greatly reduced strength when wet. Differential settlement occurs if the soils are spread over a wide area or the structure is partially founded on pockets of metastable soils.

Organic Soils. Those soils that contain significant amounts of decayed and decaying vegetation matter are organic soils. These soils have very little cohesive or friction strength and are highly compressible, even under light loads. Aside from high initial compression settlement, organic soils can be expected to compress further over very long periods of time due to continual decay of the organic constituent parts. Organic soils are characteristic of estuarine, lacustrine, and floodplain areas.

Peat, a common organic soil, is fibrous, partially decomposed organic matter or a soil containing 80 percent or more fibrous organic matter. Peat soils are dark brown or black, loose, and extremely compressible. Muskeg is a type of peat indigenous to northwestern Canada and Alaska.

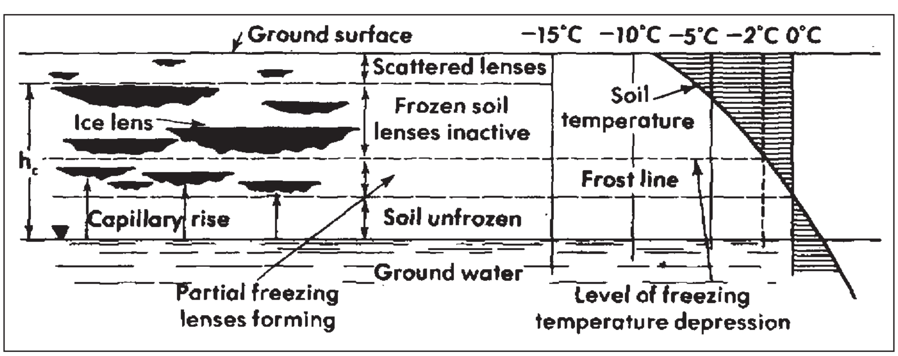


FIGURE C.17 Formation of ice lenses. (*Introductory Soil Mechanics and Foundations,* by George F. Sowers, copyright 1979. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ)

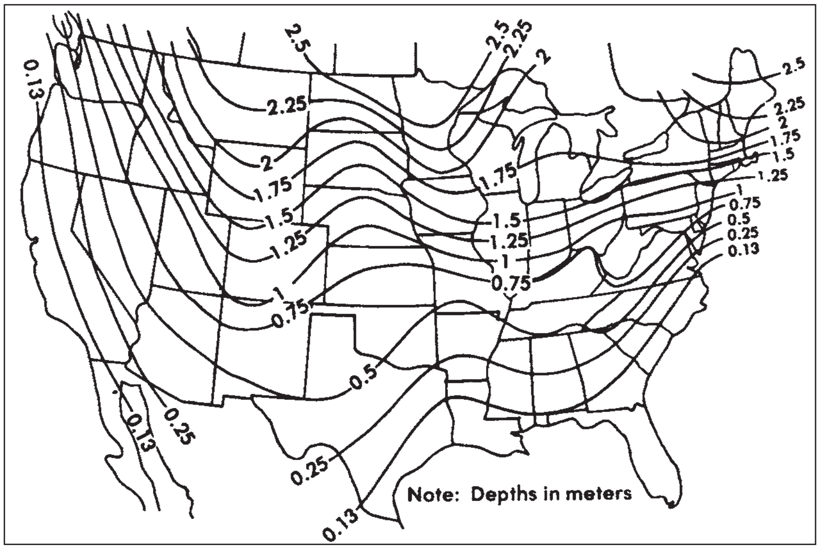


Figure C.18 Maximum frost penetration. (*Introductory Soil Mechanics and Foundations* by George F. Sowers, copyright 1979. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ)

Dispersive Clays. Certain types of soils go into suspension and become highly erodible in the presence of water (flowing or static), despite being compacted. Such soils are known as dispersive clays and often contain montmorillonite or illite minerals. These dispersive clays are not uncommon and are typically found in floodplain deposits, slope wash, lake beds, and loess.

Normally Consolidated Clays, Overconsolidated Clays, and Underconsolidated Clays. A soil is normally consolidated if the maximum pressure on an element of soil mass is equal to the present soil column pressure and the soil has fully consolidated under that pressure. That is, the compression state of the soil is due to the existing overburden weight. Otherwise, if the soil mass compression behavior is due to pressures larger than the present overburden pressure, the soil is overconsolidated. Such overconsolidated clay strata are common where significant removal of overburden has occurred over time, such as from the retreat of glaciers, long-term erosion, land movement, or lowering of the ground water table. Underconsolidated soils are those soils that are still consolidating under their own weight.

Normally consolidated clays are subject to additional long-term settlements under loads greater then the existing overburden pressure. Such long-term settlements can be reasonably estimated from tests performed on undisturbed samples (ASTM D-2435). Underconsolidated soils are soils that are still settling under the current overburden pressure.

PROJECT SETUP

A subsurface investigation is performed by geotechnical engineers. It is recommended that the owner contract separately with the geotechnical engineer to perform the work. Depending on the contract arrangements between the owner and the land development consultant, provisions may be made so that the land development consultant can contract directly with the geotechnical engineer. On the other hand, the land development consultant may have geotechnical staff and resources capable of doing the subsurface analysis. Additionally, and unless they possess the ability to do so within their firm, quite often the geotechnical engineer subcontracts with another company to perform the drilling, test pits, and collection of samples, under the engineer's direction.

Planning

Proper planning is one the most important aspects of a project. Many projects that have failed or had significant cost overruns can be attributed to poor initial planning or insufficient coordination between the developer, architect/engineer, and geotechnical engineer. Under preferable circumstances, a project should be developed as follows. Prior to the field investigation and relatively early in the development process, a meeting of the owner, land developer, architect/engineer, and geotechnical engineer should be scheduled to discuss relevant project information and establish the scope for the field investigation. Talking points in this meeting should include the following:

- Size, shape, and exact location of the project.
- Review of a site plan showing existing topography versus proposed topography, existing structures and roads versus proposed structures and roads (including buildings, retaining walls, headwalls, and bridges), and proposed stormwater management facilities. The plan should also show finished floor elevations of both the existing and the proposed structures. A preliminary or schematic plan is acceptable for this purpose.
- Type of structure, number of floors, basements, structural loads (both wall and column loads), column spacing, and settlement limits.

- Major infrastructure needs including roads, site drainage, and stormwater management facilities, particularly if they are infiltration-based designs, water and sewer mains, and any on-site wastewater treatment facilities.
- Determination of any required tree or sensitive ecosystem (wetlands, resource protection areas) preservation areas. Limits of clearing and grading should be noted and discussed to prevent field investigation in restricted areas.
- Assessment of cut and fill requirements.

Proposal

With the preceding information, the geotechnical engineer can develop a detailed scope of work to investigate the site to determine the subsurface conditions. If the investigation is conducted early enough in the development stage of the project, significant cost savings can be realized. Early investigation might indicate that the development of the site—the proposed structures, foundations, and earthwork—may be more costly than is feasible.

The field investigation can include one or all of the following: test pits, soil/auger or wash borings with standard penetration testing (SPT), cone penetrometer test (CPT), and geophysical surveys. The geotechnical engineer's proposal will typically include the following:

- Time frame to complete the investigation, (fieldwork, laboratory testing, and report preparation)
- Number and estimated depths of test borings and/or test pits that will be performed
- Type and number of laboratory tests that can be anticipated
- Estimated budget

It is important that the owner/land developer select a geotechnical engineer who is familiar with the geology, soils, and local problems in the project area.

The more information that the geotechnical engineer can obtain from the architect/engineer and from the field, the better the quality of the report and design recommendations that can be provided. The following sections provide more detailed information regarding the field investigation process.

Subsurface Investigation

Decisions for the planning and design of a project depend highly on subsurface conditions at the site. Not only is geologic and soil information necessary for design, but information on what is contained below the surface affects various project decisions as well. The subsurface investigation aids the foundation designer and helps the owner in making economic and financial decisions for the project. Knowledge of subsurface conditions, such as contaminated ground water, presence of hazardous materials (natural or manufactured), and extremely poor soil and rock conditions at the early planning stages can save the owner time and money. For example, conditions might be so egregious that the owner elects to abandon the project at this site in favor of another, where development costs may be more predictable or feasible. Although performing the subsurface exploration may be an investment up front (subsurface exploration costs can be around 0.5 percent to 1.0 percent of the total construction costs), the long-term savings often warrant such an expense. Additionally, many public agencies require subsurface information before the project is approved. The extent of this information depends on the nature of the subsurface conditions and the project. Where foundation and subsurface conditions are relatively straightforward and not complex, the information may be adequately covered by a short soils report. For complex projects with unusual or difficult conditions, the required information may be quite extensive. Local ordinances may also dictate the type of information needed.

All investigations should begin by researching available information, followed by a thorough surface reconnaissance. Available information that may be helpful includes published geologic reports, Natural Resource Conservation Service (NRCS) county soil reports, stereo air photos used for photogrammetric mapping, flood maps, hydrology maps, and information and experience at nearby sites. Based on an assessment of this information, a subsurface investigation program can be planned to obtain adequate data for analysis and design of the project. Specific objectives of the investigation normally include:

- Location and depth of soil layers, bedrock, and ground water within the depths of significant stress increases expected under a proposed structure, as well as other features that may affect the project, such as subsurface cavities, hazardous waste, and contaminated soil
- Samples of all significant materials for visual examination and classification or laboratory testing if necessary
- Field data to determine the density or compactness of all materials
- Any other special requirements based on project plans or subsurface conditions

Due to the inherent uncertainties of soil and rock behavior, the detail of the subsurface investigation is carried out to a level that balances both design requirements and cost with risk. The type of project may dictate the extent of the geotechnical report and when it is initiated. For development projects such as commercial and retail projects, the subsurface investigation is begun early in the planning phase. However, residential development (lot and street layout) may lend itself to use of Soil Conservation Service soil surveys to provide sufficient preliminary information to begin the project and defer a thorough subsurface investigation until the specific site details are finalized and the scope of the investigation refined.

Investigation Program. Soil survey reports are often available from the Natural Resources Conservation Service (previously the Soil Conservation Service). These reports delineate and describe the soils of a locality generally within the upper 6 feet. The very early NRCS soil reports were compiled mainly for agricultural purposes by the U.S. Department of Agriculture (USDA). Recently, updated reports have begun to include additional information useful in land planning and engineering design. This information can be accessed through the USDA NRCS website at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx. The reports describe the pedological soil series found in the locality, provide a map showing their location, and provide tables that equate the soil series to engineering index properties. Other tables provide data relating the soil series to wildlife habitat, building site development, sanitary facilities, construction materials, water management, physical and chemical properties, and hydrologic characteristics.

The NRCS soil survey report is an invaluable document for any development project. The information can be used throughout various stages of the development's design process. As part of the preliminary investigation, the soils should be mapped onto a scaled work drawing of the site. Soils or other subsurface conditions that are anticipated to present problems for the project (e.g., high-water table, poor bearing support, highly erodible silt) are identified on the map. These questionable areas need to be flagged in the field. The soils and subsurface conditions in the questionable areas can then be confirmed with supplemental data such as existing geotechnical reports for nearby projects or geotechnical investigations at the site. Although the NRCS soils report should not be used as the sole source of subsurface conditions for the project, it may allow the design of the project to proceed expediently.

A preliminary subsurface exploration program is sometimes advantageous to gather sufficient data to perform preliminary calculations for size and cost for foundations of major structures and to determine whether there are any subsurface conditions that will significantly impact the project. The amount of data gathered in the field during a preliminary program depends on the extent of existing data and the need for additional information for preliminary design purposes. Unanticipated field conditions may warrant extra test pits, bore holes, and additional soil samples. As details of the proposed project develop during design, additional subsurface exploration may be required to supplement the previously obtained data.

Field exploration programs should be carefully planned and laid out to obtain adequate data for design of the project. While no set rules apply to methodically laying out exploration points that cover all conceivable conditions, sound judgment should supersede any generalized rule-of-thumb exploration techniques. The number and location of the exploration points depend on the prevailing soil conditions, the variability of the soils, and proposed project details. Highly variable soil conditions warrant an increase in the number of exploration points to determine the areal extent of the various soil conditions, particularly problem soils that may be encountered. The increased number of exploration points, however, does not necessarily require an increase in the number of tests for determination of the soil's physical properties and parameters. The number of different types of soil within the stressed zone influences the number and types of laboratory tests performed. The following guidelines may be helpful in establishing acceptable boring locations:

1. For office buildings or building complexes, a boring at each corner and one in the middle as a minimum. For larger building groups, the objective might be to locate and space the borings to establish subsurface cross sections in perpendicular directions.
2. For dams, the objective is to establish geologic profiles across the valley at the longitudinal axis, at the downstream and upstream toes, and at all major hydraulic structures such as spillways, outlet works, and large culverts/conduits. Borings within the impoundment area itself may help identify the suitability of excavated soils for the dam embankment and the seepage/infiltration characteristics of the area.
3. Borings in road areas are located to obtain data for four different criteria:
   a. Shallow borings along the alignment are spaced to identify and verify areas of similar soils as anticipated from other data sources such as soil maps and aerial photographs.
   b. Borings are taken in the vicinity of major structures such as bridge abutments, piers, and retaining walls. The number of borings for abutments or piers typically is one or two. Borings for retaining walls are placed to give longitudinal and transverse subsurface profiles.
   c. Borings are taken in cut areas to determine the difficulty of excavation and slope stability. These borings are more closely spaced and deeper than the roadway alignment borings.
   d. Borings for borrow areas provide data on the suitability of the soil to be used as fill material. Depending on the size of the projected borrow area, a grid pattern with borings at 200- to 400-foot intervals may suffice.

Again it is emphasized that the actual location of the borings should depend on project details, anticipated site conditions, and what is actually encountered during the drilling. The preceding generalizations are only to provide initial guidance. Other guidelines are presented in Table C.9.

Depth of Exploration. The depth of test borings depends on two factors: (1) the magnitude and distribution of the imposed loading and (2) the subsurface characteristics. Since the basic objectives of any boring program are to determine a subsurface profile and identify engineering properties of the materials, borings should extend to a depth

TABLE C.9 Guidelines for Boring Layout

Areas for Investigation	Boring Layout
New site of wide extent	Space preliminary borings 200–500 ft apart so that area between any four borings includes approximately 10% of total area. In detailed exploration, add borings to establish geological sections at the most useful orientations.
Development of site on soft compressible strata	Space borings 100–200 ft at possible building locations. Add intermediate borings when building sites are determined.
Large structure with separate closely spaced footings	Space borings approximately 50 ft in both directions, including borings at possible exterior foundation walls at machinery or elevator pits, and to establish geologic sections at the most useful orientations.
Low-load warehouse building and large area	Minimum of four borings at corners plus intermediate borings at interior foundations sufficient to define subsoil profile.
Isolated rigid foundation, 2500–10,000 ft^2 in area	Minimum of three borings around perimeter. Add interior borings depending on initial results.
Isolated rigid foundation, less than 2500 ft^2 in area	Minimum of two borings at opposite corners. Add more for erratic conditions.
Major waterfront structures, such as dry docks	If definite site is established, space borings generally not farther than 50 ft, adding intermediate borings at critical locations, such as deep pump-well, gate seat, tunnel, or culverts.
Long bulkhead or wharf wall	Preliminary borings on line of wall at 200-ft spacing. Add intermediate borings to decrease spacing to 50 ft. Place certain intermediate borings inboard and outboard of wall line to determine materials in scour zone at toe and in active wedge behind wall.
Slope stability, deep cuts, high embankments	Provide three to five borings on line in the critical direction to provide geological section for analysis. Number of geological sections depends on extent of stability problem. For an active slide, place at least one boring upslope of sliding area.
Dams and water retention structures	Space preliminary borings approximately 200 ft over foundation area. Decrease spacing on centerline to 100 ft by intermediate borings. Include borings at location of cutoff, critical spots in abutment, spillway, and outlet works.

that provides a reasonable comfort level for design analysis purposes. As in selecting the location of borings, this is a judgment decision to be made by the geotechnical expert and the person designing the foundation and structure. A suggested rule of thumb is "to carry borings to such depth that the net increase in soil stress under the weight of the structure is less than 10% of the average load of the structure, or less than 5% of the effective stress in the soil at that depth, whichever gives the lesser depth, unless bedrock or dense soils known to lie on rock are encountered first" (American Society of Civil Engineers, 1976).

The following is presented as a guide for determining boring depths:

1. Extend borings through any unsuitable and questionable material into firm stable soils that are capable of sustaining the imposed loads without excessive settlement.
2. Borings should extend a sufficient depth into any apparent rock to ensure the existence of bedrock rather than a boulder.
3. Explorations along roads are carried to depths of 5± feet below subgrade in areas of light cut and fill where no adverse subsurface conditions exist. In areas of deep cuts and large embankments, the depth of exploration depends on the topography and nature of the underlying soils.
4. In residential areas where houses have relatively shallow foundations, the depth depends on the nature of the subsurface soils. Typically, the depth of exploration will be 5 to 10 feet below the foundation. In most cases, borings will not be needed at every dwelling location.
5. For other buildings with substantial loadings, the depth of exploration beneath the footing extends 1.5 to 2 times the least dimension of the structure. In the case

where the loading is carried on piles or caissons, the exploration must extend a sufficient depth into a competent bearing stratum to carry the imposed loading and to be sure that underlying weaker material is not present.

6. In borrow areas, the depth of exploration extends to the depth required to provide the amount of suitable material needed.

Other guidelines are presented in Table C.10.

The Soils Report

The geotechnical consultant provides the land development engineer with the geotechnical information in the form of a report. This information impacts not only the preliminary design and layout of the development, but also the final engineering design. Some of this information may be used in developing part of the specifications, which will impact the contractor's approach to construction and his or her bid estimates. Data included in the report will be of specific use for different aspects of design and construction. For example, the land development engineer is interested in permeability rates and ground water elevations in order to design SWM facilities, bearing capacity as it relates to appropriate pavement sections, and slope stability angles for purposes of detailed grading plans. From a construction perspective, the earthwork contractor is concerned about the difficulty of excavation, the existence of bedrock, the "rippability" of the rock, the suitability of excavated material for reuse, and the presence of ground water. The foundation contractor is interested in confirming that the soil is capable of providing suitable bearing support or determining whether there will be difficulty in driving piles or drilling shafts, as well as knowing their expected depths.

The geotechnical report is typically organized as follows, but depending on the nature of the project, some of the listed topics may not be included:

- Scope and purpose of the investigation
- General description of the proposed project to include column and wall load, settlement limits, infrastructure improvements, and building characteristics, such as finished floor elevations
- Geologic conditions of the site that describe the physiographic region, the geologic formations, and the predominant soils
- Drainage characteristics and facilities
- Methods and details of the exploration program
- Types and results of laboratory tests performed on the samples
- Description of the site including topography, ground cover, structures (if present), and any unusual conditions

TABLE C.10 Guidelines for Boring Depths

Areas for Investigation	Boring Layout
Large structure with separate closely spaced footings	Extend to depth where increase in vertical stress for combined foundations is less than 10% of effective overburden stress. Generally, all borings should extend no less than 30 ft below lowest part of foundation unless rock is encountered at shallower depth.
Isolated rigid foundations	Extend to depth where vertical stress decreases to 10% of bearing pressure. Generally, all borings should extend no less than 30 ft below lowest part of foundation unless rock is encountered at shallower depth.
Long bulkhead or wharf wall	Extend to depth below dredge line between ¾ and 1½ times unbalanced height of wall. Where stratification indicates possible deep stability problem, selected borings should reach top of hard stratum.
Slope stability	Extend to an elevation below active or potential failure surface and into hard stratum, or to a depth for which failure is unlikely because of geometry of cross section.
Deep cuts	Extend to depth between ¾ and 1 times base width of narrow cuts. Where cut is above groundwater in stable materials, depth of 4–8 ft below base may suffice. Where base is below groundwater, determine extent of pervious strata below base.
High embankments	Extend to depth between ½ and 1¼ times horizontal length of side slope in relatively homogeneous foundation. Where soft strata are encountered, borings should reach hard materials.
Dams and water retention structures	Extend to depth of ½ base width of earth dams or 1–1½ times height of small concrete dams in relatively homogeneous foundations. Borings may terminate after penetration of 10–20 ft in hard and impervious stratum if continuity of this stratum is known from reconnaissance.

- Details of subsurface conditions determined from the exploration and testing program
- Ground water characteristics and any seasonal or tidal influence that might occur at the site
- Details of the analysis used for design evaluations
- Conclusions and detailed design and construction recommendations for critical project components including footings and foundations, pavement sections, retaining walls if required or as a suggested design alternative, and construction recommendations for such requirements as dewatering and slope stabilization
- Plan showing the locations of borings and proposed building layout
- Logs (results) of the borings (see Figure C.19), as well as subsurface profiles
- Photographs of the site at the time of field investigation

Foundation Recommendations

- Based on the field exploration and laboratory analyses, the most feasible foundation type is presented. The type of foundation depends on the subsurface conditions and the anticipated structural loads. Typical foundation types include shallow foundations, mat foundations, and deep foundations.
- Shallow foundation recommendations typically present a net allowable soil bearing pressure at a specific depth below the surface. The allowable bearing pressure takes into consideration both bearing capacity (resistance against shear failure) and expected settlement performance (usually total less than 1 inch; differential less than ¾ inch). The allowable bearing pressure at the column footing is presented as pounds per square foot. The allowable bearing pressure along a continuous wall footing is presented as pounds per linear foot. The recommendations also present the estimated total and differential settlements that are anticipated from the structural loads.
- Deep foundations are recommended when the near surface soils are poor or when the estimated settlement is not acceptable. Deep foundations include drilled piers/caissons, driven piles (wood, concrete, or steel), and augered cast-in-place piles. The recommendations typically include the type of pile, pile size, allowable capacity, and estimated length of the pile.

Pavement Recommendations. There are two main types of pavement: flexible and rigid. Flexible pavement is constructed of asphaltic concrete, and rigid pavements are constructed of portland concrete. Porous or pervious pavement is being used more and more today to help designers control stormwater runoff issues. The porous pavement can be either a special asphaltic paving material or open jointed concrete blocks that allow stormwater to permeate through the pavement section at a higher rate than in a normal pavement design. The runoff is temporarily retained below the pavement within an aggregate base and discharged to a storm sewer system or infiltrated into the underlying in situ soils. "The principal components of pervious pavement systems are porous pavement permeable pavement blocks, a bedding (choker) course, an optional filter fabric between the bedding course and the aggregate base in permeable pavement block systems, an open-graded aggregated base with a high void ratio, filter fabric to separate the aggregate base from the underlying soils and an underdrain that is connected to the storm drain system" (Fairfax County Public Facilities Manual, 6-1304 Pervious Pavement 98-97-PFM). The designer should check with the local municipality for the individual requirements for pervious pavement such as zoning ordinance or design requirements including the underlying substrate infiltration rate. Conditions that influence the design can be summarized as follows:

- Bearing values of the subgrade. These can be represented by a California Bearing Ratio (CBR, ASTM D1883) for the design of flexible pavements, or a modulus of subgrade reaction (k) for rigid pavement structures (see Table C.11).
- Ground water conditions, variations in water levels, expansive considerations, and necessity for underdrains.
- Vehicular traffic, in terms of the number and frequency of vehicles and their range of axle loads.
- Typical recommendations include the thicknesses of each layer of the pavement section including the asphaltic concrete or Portland cement concrete, base course, subbase (if required), and existing subgrade requirements. Also given are the compaction requirements.

Retaining Wall Recommendations. Typically, the geotechnical engineer provides the following soil parameters so that the structural engineer can design and specify any retaining walls that may be required:

P_a = active earth pressure

γ = unit weight of backfill for both the natural soil and fill soils behind the retaining wall

K_a = coefficient of active earth pressure

β = angle between backfill surface line and a horizontal line if known

ϕ = angle of internal friction of the backfill material

P_p = passive earth pressure

K_p = coefficient of passive earth pressure

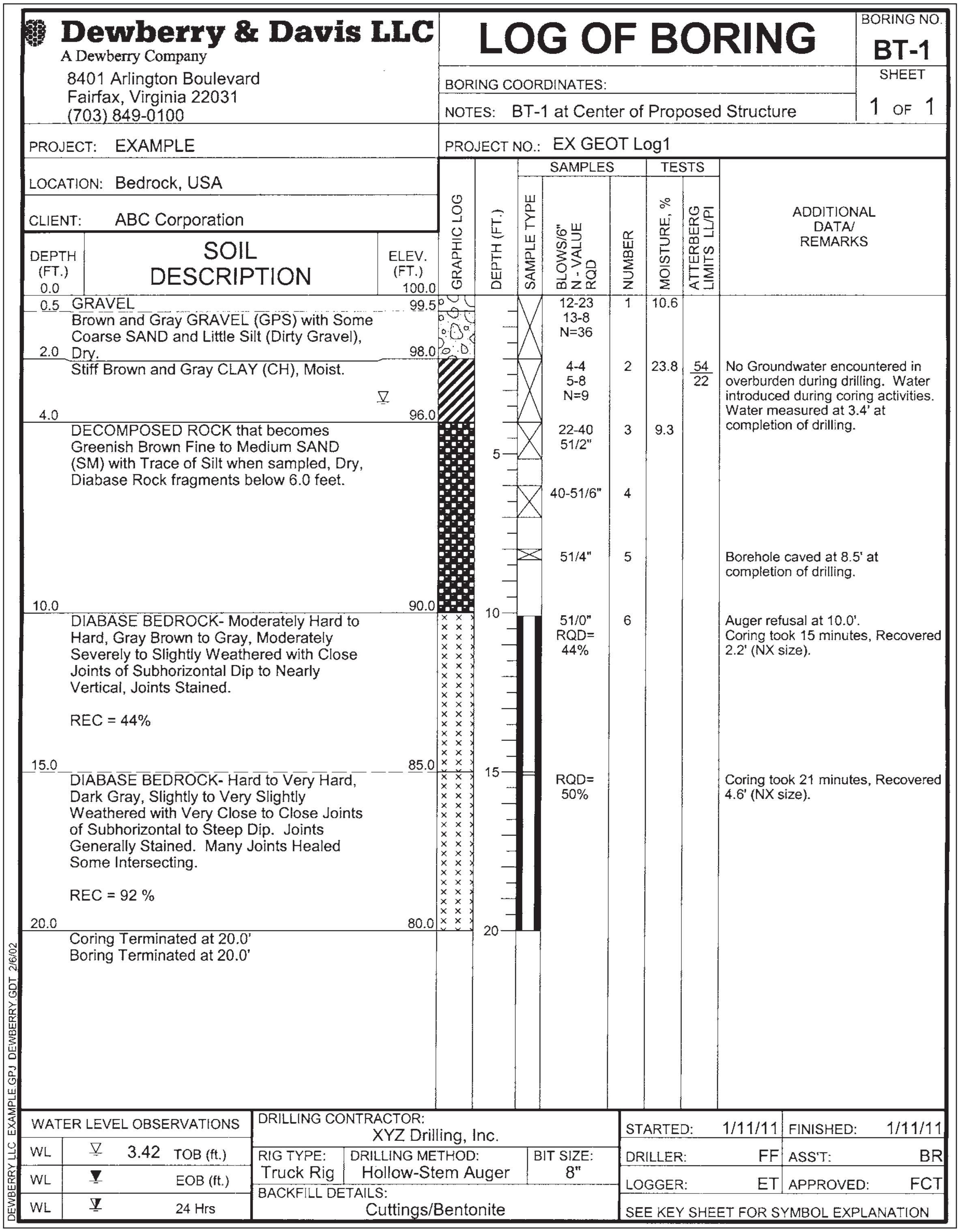


FIGURE C.19 Log of boring.

Construction Recommendations/Considerations. This section of the soils report can be the smallest or the largest, depending on the subsurface conditions and the planned development program. Depending on the nature of the project, some of the listed recommendations/considerations may or may not be included:

- *Topsoil:* May include removal of excessively organic topsoil beneath pavements, floor slabs, structural fills, and shallow foundations.

- *Earthwork:* Depending on the topographic and geologic conditions at the site, extensive earthwork may or

TABLE C.11 Soil Characteristics Pertinent to Roads and Airfields

Major Divisions	Letter	Name	Value as Subgrade When Not Subject to Frost Action	Value as Subbase When Not Subject to Frost Action	Value as Base When Not Subject to Frost Action	Potential Frost Action	Compressibility and Expansion	Drainage Characteristics	Compaction Equipment	Typical Design Values: Unit Dry Weight (lb/ft^2)	Typical Design Values: CBR	Typical Design Values: Subgrade Modulus (lb/in.^{3})
Coarse-grained soils												
Gravel and gravelly soils	*GW*	Well-graded gravels or gravel-sand mixtures, few or no fines	Excellent	Excellent	Good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	125–140	40–80	300–500
	GP	Poorly graded gravels or gravel-sand mixtures, few or no fines	Good to excellent	Good	Fair to good	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller, steel-wheeled roller	110–140	30–60	300–500
	*GM d**	Silty gravels, gravel-and-silt mixtures	Good to excellent	Good	Fair to good	Slight to medium	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller, close control of moisture	125–145	40–60	300–500
	*u**		Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	115–135	20–30	200–500
	OC	Clayey gravels, gravel-sand clay mixtures	Good	Fair	Poor to not suitable	Slight to medium	Slight	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	130–145	20–40	200–500
Sand and sandy soils*	*SW*	Well-graded sands or gravelly sands, few or no fines	Good	Fair to good	Poor	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	110–130	20–40	200–400
	SP	Poorly graded sands or gravelly sands, few or no fines	Fair to good	Fair	Poor to not suitable	None to very slight	Almost none	Excellent	Crawler-type tractor, rubber-tired roller	105–135	10–40	150–400
	*SM d**	Silty sands, sand silt mixtures	Fair to good	Fair to good	Poor	Slight to high	Very slight	Fair to poor	Rubber-tired roller, sheepsfoot roller, close control of moisture	120–135	15–40	150–400

	*u**		Fair	Poor to fair	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100–130	10–20	100–300
	SC	Clayey sands, sand-clay mixtures	Poor to fair	Poor	Not suitable	Slight to high	Slight to medium	Poor to practically impervious	Rubber-tired roller, sheepsfoot roller	100–135	5–20	100–300
Fine-grained soils Silts and clays 1.1 is less than 50	*ML*	Inorganic silty and very with fine sands, rock floor, silty or clayey silts slight plasticity	Poor to fair	Not suitable	Not suitable	Medium to very high	Slight to medium	Fair to poor	Rubber-tired roller, sheepsfoot roller, close control of moisture	90–130	15 or less	100–200
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	Poor to fair	Not suitable	Not suitable	Medium to high	Medium	Practically impervious	Rubber-tired roller, sheepsfoot roller	90–130	15 or less	50–150
	OL	Organic silts and organic silt clays of low plasticity	Poor	Not suitable	Not suitable	Medium to high	Medium to high	Poor	Rubber-tired roller, sheepsfoot roller	90–105	5 or less	50–100
Silts and clays 1.1 is greater than 50	*MH*	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	Poor	Not suitable	Not suitable	Medium to very high	High	Fair to poor	Sheepsfoot roller, rubber-tired roller	80–105	10 or less	50–100
	CH	Inorganic clays of high plasticity, fat clays	Poor to fair	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	90–115	15 or less	50–150
	OH	Organic clays of medium to high plasticity, organic soils	Poor to very poor	Not suitable	Not suitable	Medium	High	Practically impervious	Sheepsfoot roller, rubber-tired roller	80–110	5 or less	25–100
Highly organic soils	*Pt*	Peat and other highly organic soils	Not suitable	Not suitable	Not suitable	Slight	Very high	Fair to poor	Compaction not practical			

Courtesy of The Asphalt Institute. 1986. *Soils Manual for Design of Asphalt Pavement Structures*. MS-10, College Park, MD.
*d** indicates $LL \leq 25$ and $PI \leq 5$, otherwise *u**.

may not be required to achieve the proposed final project grades at the site. Cuts and fills must be carefully designed and properly constructed to limit differential settlements across the site as well as potential slope failures.

- *Existing fill soils:* Existing fill soils are typically erratic in composition and consistency and are not reliable to support building foundations without soil improvements. If fill soils are encountered at the site, a description of the material (construction debris, pavement debris, trash or soil that was dumped) should be given. If the fill material is not suitable to support the planned development, then the depth of removal should be given. Depending on composition, occasionally existing fill soils can be reused in other nonstructural areas of the site to avoid expensive hauling of waste soils off-site and/or replacement.

- *Fill requirements:* The geotechnical engineer should specify what the fill requirements are at the site. The requirements should be separate for structural fill (fill material beneath foundations) and fill outside the building footprint beneath sidewalks and pavements.

- *Compaction:* Compaction requirements should be given for the fill being placed throughout the site. The recommendations should include the thickness of the layer being placed, compaction effort, and any allowable deviations from optimum moisture content during field placement.

- *Floor slab-on-grade:* Depending on the exiting soils, recommendations may be given to improve the near surface soils beneath the slab-on-grade foundations. This may include proof-rolling the area or replacement of soft or loose materials.

- *Ground water:* The report should discuss anticipated ground water problems, such as perched water considerations, ground water level, and any anticipated fluctuations to this depth based on seasonal and local precipitation factors.

- *Aboveground and underground utilities:* Existing, functional aboveground and underground utilities that are present should be discussed if they will be within the construction area and if they will need to be realigned and/or removed prior to development or protected during development.

- *Seasonal frost:* Frost heave and thaw settlement of seasonally frozen ground can subject buried structures to large forces and destructive movement. The depth for frost protection in the area should be given. All exterior foundations should be below this frost depth.

- *Drainage control during construction:* Adequate drainage during the construction operation needs to be considered. This can be accomplished by maintaining positive slopes, temporary ditches, swale features, and pumping equipment (dewatering facilities) to maintain the soils in a dry condition.

- *Sheeting and shoring:* Shoring may be necessary in deep excavations where there is a limited space to lay back the slopes at a stable repose. A discussion of the natural soils should address the existing conditions (loose to very loose or soft zones) and necessary measures to protect the excavation. Safety and health requirements on-site shall conform to local, state, and federal regulations.

- *Inspections:* Many geotechnical reports and design drawings specify that various inspections should be performed during construction. They can vary from a visual inspection by a geotechnical engineer to verify that the soils described in the report are those encountered during construction to in situ testing by a geotechnical engineer. Typically, inspections are required for bearing capacity of shallow foundations, pile load tests to verify pile capacities, compaction testing of fill areas, and proof-rolling of pavement areas. When practical, the geotechnical engineer of record should be the engineer who performs the inspection.

Implementation of the geotechnical recommendations presented in the report is the responsibility of the land development engineer. For the most part, the land development engineer can merely incorporate the necessary details—items such as typical pavement sections, dam embankment requirements, and adequate grading or slope provisions—into the final design drawings. Specialty design features such as retaining walls or corrective measures and ground improvements, if warranted, may require a significant design effort. Further collaboration with the geotechnical engineer and/or a subcontractor such as a structural engineer may also be required. Design considerations for these advanced geotechnical applications, increasingly common in land development projects, are elaborated as follows.

LATERAL EARTH PRESSURE AND RETAINING WALLS

Lateral earth pressure is a significant design parameter associated with land development. Retaining walls, foundation walls, braced and unbraced excavations, bridge abutments, underground tunnel structures, and their headwall and wingwalls are all subject to lateral earth pressures and thus require a quantitative estimate of the forces acting on the structure (Bowles, 1982).

Earth-retaining structures facilitate an abrupt change in grade where two neighboring masses of earth must be maintained at differing elevations. The urban development setting has promulgated the use of retaining structures to allow greater unit density. When designed properly, retaining structures, although not the most economical solution when compared to nonstructural or conventional earth-grading methods, may be the only feasible engineering solution in many cases.

Preliminary cost estimates and comparisons to alternative (nonwall) solutions often reveal retaining wall solutions that appear economical: "However, on detailed analyses of the design drawings and cost estimates it is often observed that the construction of the retaining wall has been given only trivial consideration, without paying attention to the often costly details" (Rodriguez, 1988). Many wall designs are engineered without proper consideration of substantial and effective wall drains, control of backfill material, and proper evaluation of special foundation conditions. Improperly designed walls are predisposed to failure and a greatly reduced life span. Retaining walls are often associated with roadways and parking lots and thereby receive a great deal of visual traffic. Distressed or failed retaining walls can lead to a poor perception of the land development engineer and tarnish the reputation of the design firm.

Earth Pressures against Walls

Earth pressure is the force per unit area exerted by the soil on the retaining structure. *Lateral,* meaning "sideways," combined with *earth pressure* results in the term *lateral earth pressure,* which is the force or pressure exerted principally in the horizontal direction against the retaining structure. Retaining structure design considers the analysis and determination of these lateral earth forces, their magnitude, and their applied direction (Liu, 1937).

The magnitude of the earth pressure depends on the physical properties and characteristics of the soil; the soil-structure interaction, which occurs at the interface of the soil mass and the adjoining retaining structure; and the deformation behavior of the soil-wall system. The directions of the applied forces are influenced by the geometry of the retaining wall and the retained earth within a given distance to the wall. Since movement of the retaining wall is a primary factor in developing the earth pressure forces acting against the wall, and the characteristics of the soil influence these earth pressure forces, the design of the wall system becomes indeterminate.

Design engineers typically calculate two categories of earth pressures, *active earth pressure* and *passive earth pressure,* when designing retaining structures. A third category, *earth pressure at rest,* reflects a condition where absolutely no movement of the wall system occurs.

Active earth pressures are developed when the soil mass behind the wall system moves outward as a result of some horizontal movement of the wall. Movement of the wall in the opposite direction (i.e., toward the soil) in turn mobilizes the shear strength of the soil and is referred to as passive earth pressure.

Analysis and design of unbalanced fill retaining walls and structures requires an in-depth knowledge of soil mechanics and use of appropriate computational methods beyond the scope of a general engineer without the requisite training and experience. Indeed, these are structural walls comprising soil and structural members to support numerous live loads and should be addressed appropriately by professionals trained and experienced in this area.

Two of the earliest earth pressure solutions used to satisfy static equilibrium ($\Sigma F_h \Sigma F_v = 0$) of the retaining wall system were the Coulomb theory (1776) and later the Rankine theory (circa 1857). Because of its simplicity, we consider only the Rankine theory.

The Rankine theory is based on several assumptions:

- No adhesion or friction exists between the wall and the backfill.
- The ground surface behind the wall is either flat or sloping.
- A sliding wedge-type failure occurs along an assumed failure plane (i.e., shear plane), which is represented as a function of the soils angle of internal friction ϕ.
- The back of the wall is vertical.

Figure C.20 represents the active and passive conditions associated with Rankine analysis of wall design.

The equations for computing lateral earth pressure based on the Rankine theory are as follows (Liu, 1937, p. 365):

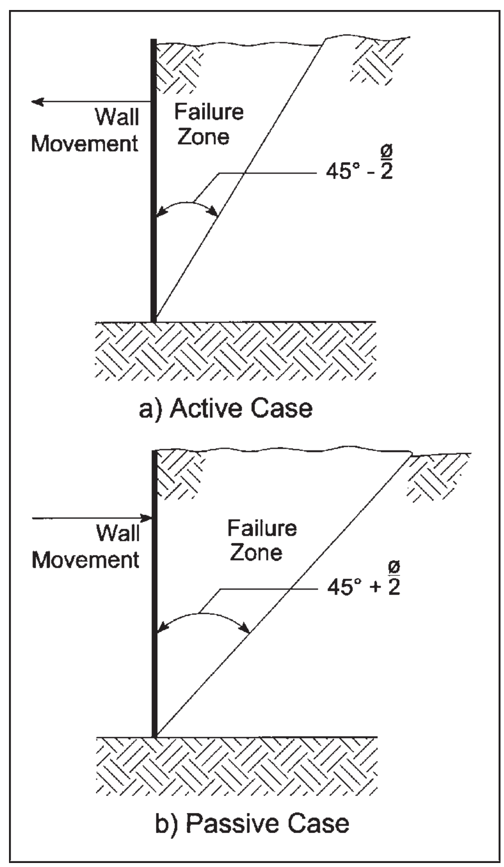


FIGURE C.20 Active and passive failure zones for Rankine theory.

$$P_a = \frac{1}{2}\gamma H^2 K_a \qquad \text{(C.7)}$$

$$K_a = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \qquad \text{(C.8)}$$

$$P_p = \frac{1}{2}\gamma H^2 K_p$$

$$K_a = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi}} \qquad \text{(C.9)}$$

Where:
P_a = active earth pressure
γ = unit weight of backfill soil
H = height of the wall
K_a = coefficient of active earth pressure
β = angle between backfill surface line and a horizontal line
ϕ = angle of internal friction of the backfill material
P_p = passive earth pressure
K_p = coefficient of passive earth pressure

When the backfill behind the wall is horizontal (i.e., level) $\beta = 0°$, the coefficients of earth pressure become:

$$K_a = \frac{1 - \sin\phi}{1 + \sin\phi} \qquad \text{(C.10)}$$

$$K_p = \frac{1 + \sin\phi}{1 - \sin\phi} \qquad \text{(C.11)}$$

For convenience, Table C.12 provides Rankine earth pressure coefficients for level backfill ($\beta = 0°$ for various ϕ values).

The resultant lateral earth pressure forces acting on a simplified wall section are depicted in Figure C.21. Special attention is given to walls with inclined backsides, as depicted in Figure C.21*b*.

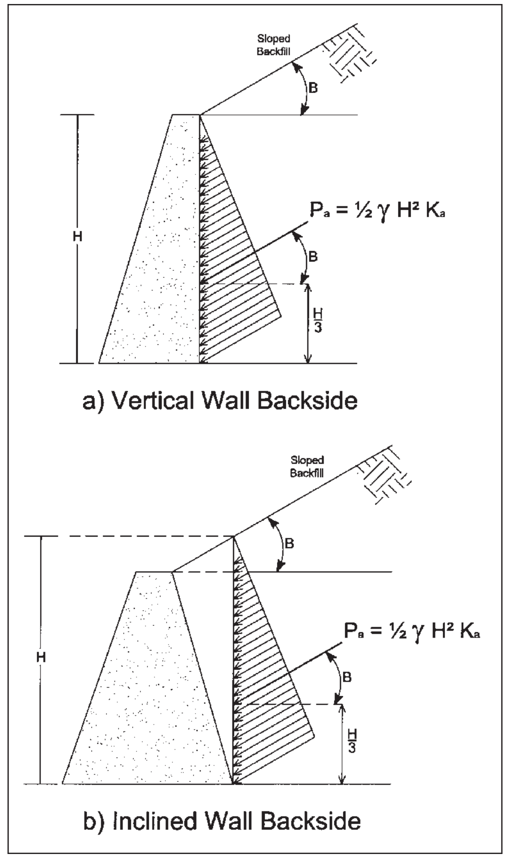


FIGURE C.21 Lateral earth pressure for Rankine theory.

Design Considerations for Retaining Walls

Retaining wall performance has a checkered past, and for many designers the visual intensity of a failed or failing wall system can mar their reputation in the industry.

Statistical studies of retaining wall failures are provided in Figure C.22 and can be summarized as follows:

- Improper design of the drainage system and/or the walls' foundation base is the main cause of retaining wall failure.
- Clay soils as backfill or as foundation bearing material are involved in most retaining wall failures.

Structural failures of the wall system could be a result of the walls' structural integrity, but are most probably caused by the inability of the designer and/or geotechnical engineering to recognize one or more of the unique soil or loading conditions that could dramatically impact the forces on the wall. Improper construction practices also lead to premature wall failures. The practical designer should consider:

- Proper drainage through redundant methods, including proper surface drainage, weep holes, longitudinal drain pipes, and/or commercial drainage products
- Proper free-draining backfill material and filter layers to protect the drainage system from becoming clogged
- Detailed plans and specifications and adequate field compaction testing and inspection oversight during construction (inspection of retaining wall drainage and backfill operations are often omitted)

TABLE C.12 Rankine Earth Pressures for Level Backfill

Φ	10°	12.5°	15°	17.5°	20°	22.5°	25°	27.5°	30°	32.5°	35°	37.5°	40°
K_a	0.70	0.64	0.59	0.49	0.45	0.45	0.41	0.37	0.33	0.30	0.27	0.24	0.22
K_p	1.42	1.55	1.70	1.86	2.04	2.24	2.46	2.72	3.00	3.32	3.69	4.11	4.60

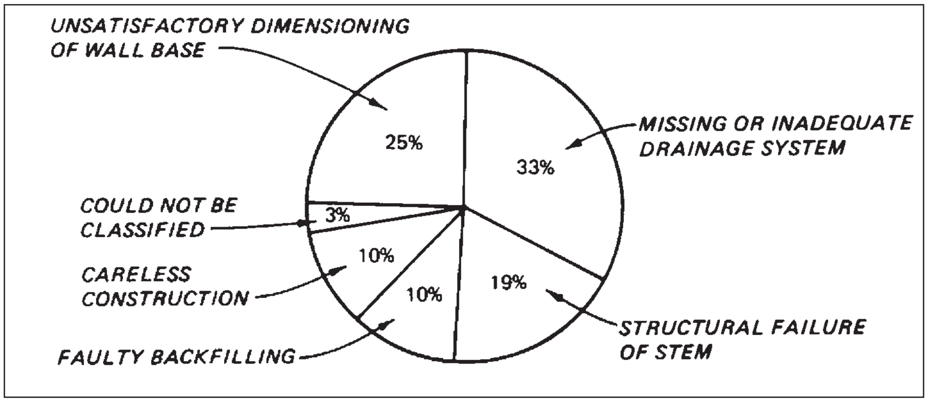


Figure C.22 Causes of failure of rigid concrete retaining walls.

- Insufficient geotechnical exploration and laboratory testing prior to the design stage, resulting in the use of assumed soil parameters with inadequate safety factors
- Excessive backfill compaction and/or use of heavy equipment adjacent to the top of the wall, which can induce very high residual pressures against the wall

Types of Retaining Walls

Retaining walls come in many different styles, shapes, materials, and design complexities. However, most retaining walls can be classified into one of the following types: gravity, cantilever, anchored, or mechanically stabilized earth (MSE).

The type of wall selected for a particular project is often a function of constructibility, aesthetics, and, of course, economy (Fang, 1991). Gravity retaining walls have been used for centuries and can be found in all walks of life. The majority of walls constructed in the last hundred years or so have been cantilever walls constructed of reinforced concrete.

Over the last 25 years, mechanically stabilized earth (MSE) walls have grown in popularity, especially in highway construction. MSE walls utilize the natural forces of an engineered fill with small quantities of materials in a composite arrangement of equilibrium.

The basic components of MSE walls consist of soil, reinforcement, and facing elements. A variety of facing elements and reinforcement are being used in MSE walls. Metal strips, steel rods, woven geotextile fabrics, and high-strength plastic geogrids have all been successfully used as reinforcement materials. See Figure C.23.

Likewise, facing materials have evolved over recent years

Figure C.23 Photo reinforced earth wall.

and come in a variety of material shapes, architectural finishes, and colors. Facing elements constructed of precast concrete panels, prefabricated metal sheets, welded wire mesh, and, in some cases, plastic geogrids have all been used successfully. The popularity of MSE walls is related to many factors the most significant of which is cost. MSE walls have proven very cost efficient compared to their traditional counterparts. This is especially true when the wall is in a fill condition with a surface area greater than 2000 square feet and an average wall height of 10 feet.

The advantages and disadvantages of MSE wall systems, summarized from Mitchell et al. (1986) (ret & flood walls) are discussed as follows.

Advantages

- Mechanically stabilized backfill systems are economical when compared to conventional retaining walls.
- Construction of mechanically stabilized backfill systems usually is easy and rapid. It does not require skilled labor or specialized equipment. Many of the components are prefabricated, allowing relatively quick construction.
- Regardless of the height or length of the wall, the structure remains stable during construction.
- When compared to conventional retaining walls, mechanically stabilized backfill systems are relatively flexible and can tolerate large lateral deformations and large differential vertical settlements (when this is anticipated, vertical sliding joints can be installed at intervals to compensate for movement). The flexibility of mechanically stabilized backfill systems allows the use of a lower factor of safety for bearing capacity design than conventional, more rigid structures.
- Mechanically stabilized backfill systems are potentially better suited for earthquake loading than conventional retaining walls because of the flexibility and inherent energy absorption capacity of the coherent earth mass. In designing mechanically stabilized backfill systems for earthquake regions, provision should be made for slippage of reinforcement elements rather than tension failure of the elements, resulting in a ductile structure (McKittrick, 1979).
- Because of their flexibility and mass, mechanically stabilized backfill systems are capable of withstanding dynamic loads imposed by wheel loads.
- Geosynthetic reinforcement is stable under chemical and biological conditions normally occurring in soils. Since facing elements play only a secondary structural role, a greater flexibility is available to meet aesthetic requirements than for conventional retaining walls. Facing arrangements range from concrete panels of various shapes, textures, and colors to provision of vegetation at the exposed face of the soil.

Disadvantages

- Corrosion of metallic reinforcement occurs and must be assessed on a project basis by determining the potential aggressiveness of the soil. Special coatings such as galvanized zinc and resin-bonded epoxy are used with a sacrificial thickness of steel added in the design to give the required service life.
- Although geotextile and geosynthetic reinforcement is a robust material, some allowance must be made for decrease in strength due to abrasion during construction. This varies with the type of reinforcement material.
- Different polymers and fabrics have different creep characteristics. Allowable loads in the grid should be selected based on allowable deformations, as well as the results of creep tests (10,000 hours).
- The construction of mechanically stabilized embankments in cut areas requires a wider excavation than conventional retaining walls.
- Postexcavation behind the mechanically stabilized wall is restricted.

Segmental retaining wall systems are very much like MSE wall systems except that the facing units are usually constructed of relatively small precast concrete block units with aesthetic face finishes; the earth reinforcing is usually geogrid. Because of their aesthetic appeal, segmental walls are often used in land development projects. Keystone and Allan Block are two proprietary segmental wall systems that have been used on some projects.

Modular wall systems like MSE walls have grown in popularity in recent years. Modular components come in a variety of shapes and designs and are usually fitted with a type of interlocking mechanism that forms a composite wall system.

Most modular walls systems are designed as gravity walls and are especially popular where aesthetics are an important factor. One of the more well-known modular systems is the Criblock system. See Figure C.24. Crib walls are constructed with some type of exoskeleton elements made of wood, precast concrete, or steel and filled with compacted fill. See Figure C.25.

The advantages and disadvantages of the precast concrete modular systems are provided here (Mitchell and Villet, 1986, extracted from *Retaining and Flood Walls,* ASLE, 1994):

Advantages of Modular Systems

- Modular systems are economical when compared to conventional retaining walls in cut situations, particularly where the retaining wall has a total surface area greater than 500 square feet and average wall heights greater than 8 feet.
- Assembly of the wall components requires no fasteners and the modules may be reused easily and economically.

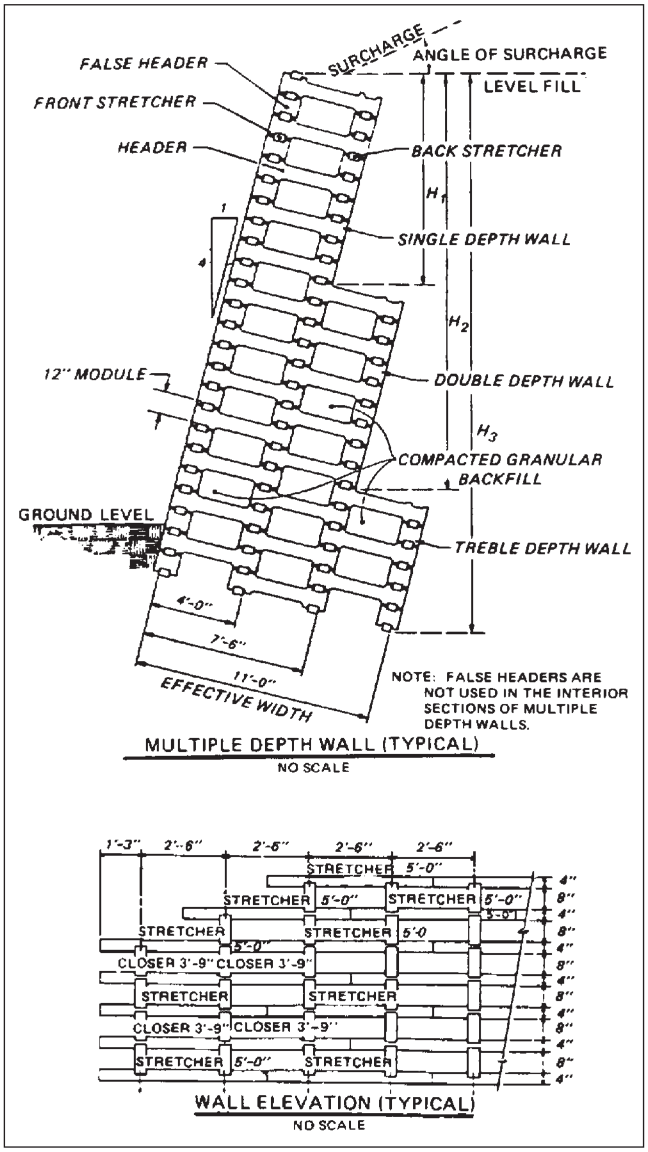


FIGURE C.24 Schematic diagram of Criblock retaining wall. (From Retaining and Floodwalls, ASCE 1994. Reprinted with permission from American Society of Engineers)

FIGURE C.25 Photo of a crib wall.

- The precast concrete modular retaining wall does not utilize reinforcing elements and therefore is not subject to corrosion damage.
- Excavation behind the precast concrete modular retaining wall does not adversely influence the stability of the system as might occur for the mechanically stabilized wall.

Disadvantages of Modular Systems

- The precast concrete modular retaining wall could sustain cracking of interior connecting members due to relatively small (0.5 foot per 100 feet of wall length) longitudinal differential settlement tolerance.

Various engineering companies involved will provide site-specific plans and limited designs for their proprietary systems. Stability is evaluated in a manner similar to that for a conventional gravity retaining wall. For stability calculations, the interlocking precast concrete modular system is assumed to behave as a single coherent block. The system must be stable against sliding along the base of the structure, overturning about the toe of the wall, bearing capacity failure of the foundation soil, differential settlement, and overall slope stability.

SLOPE STABILITY

A slope refers to an earth mass, natural or man-made, whose surface forms an angle with the horizontal. Land development practices usually include engineering design and construction of man-made slopes such as those found in embankments, earth dams, levees, foundation excavations, and trenches, and natural slopes found in hills, mountains, riverbanks, and coastal boundaries.

No slope, natural or man-made, is completely stable. Gravitational forces combined with climatic changes, especially changes involving water, are forever altering slopes. Occasionally slopes are altered or influenced by earthquakes, glaciers, or wind.

Slope stability is measured by its factor of safety, the ratio of the resisting forces (or moments) to the driving forces (or moments). The factor of safety is associated with several different soil parameters. For example, the factor of safety with respect to strength F_s is the ratio of available (i.e., maximum) strength to the required strength to sustain a load. In terms of the Coulomb equation, this is written as:

$$(\mathrm{FS})_s = \frac{(c + \sigma \tan \phi)_{\mathrm{avail}}}{(c + \sigma \tan \phi)_{\mathrm{req}}} \tag{C.12}$$

The factor of safety with respect to cohesion F_c is the ratio between actual cohesion and the cohesion required for stability. Similarly, the factors of safety with respect to friction and critical height[2] are:

[2]Critical height is defined as the maximum height for which the slope remains stable.

$$(FS)_\phi = \frac{(\sigma \tan \phi)_{avail}}{(\sigma \tan \phi)_{req}}$$

$$(FS)_H = \frac{H_{avail}}{H_{req}} \tag{C.13}$$

respectively. For dry granular soils with $c = 0$, the factor of safety is (tan φ)/(tan β), where β is the angle of the slope with respect to the horizontal. The factor of safety must be greater than 1 for a slope to be considered stable. In practice, a factor of safety of about 1.5 is desirable.

From this discussion, the following general statements can be inferred regarding slope stability:

1. Since the shear strength of granular soils increases with increased normal stress, the stability of a granular slope does not decrease as the height increases.

2. The stability of a day slope decreases as the height increases, since the shearing strength of a clay is independent of the normal stress.

There are numerous methods available to perform slope stability analysis. Most are described in soil mechanics and geotechnical engineering texts. The conditions, parameters, and assumptions, such as soil moisture conditions, kinematics of slope failure, shear strength, density, and slope geometry, vary considerably for each method. The level of reliability of these factors dictates the acceptable factor of safety and the method used for the analysis. Most cases require the analysis to account for seepage, various moisture conditions, and soil stratification. The geotechnical report typically provides the results from the analysis and recommendations for slope angles. Despite the apparent similarity of the engineering properties of the soils on a site, the recommended slope angles may vary depending on the function of the slopes. Soils reports often recommend different slope angles for road embankments, cut slopes, slopes around stormwater management ponds, and so on. Maintenance considerations sometimes dictate that a slope should be flatter than required for adequate stability.

Analysis and construction of an embankment that is strong, incompressible, and stable requires specifying a soil with certain engineering properties and characteristics. Ideally, the specified soil is within haul distance of the site or, even better, available as excess at the site. Of course, the embankment is only as stable as the underlying foundation soil.

The mode of failure of an embankment depends on the strength of the fill material, the strength of the underlying soil, and the drainage characteristics of both. Fills on deep soils with low strength fail due to inadequate bearing capacity. Reducing failure potential in such cases includes the use of lightweight fill material, flat slopes for the embankment, or a counterweight buttress at the toe. If the weak underlying soil stratum is not very thick, it may be more economical to remove and replace it with an adequate foundation soil. In the worst case, where neither of the two preceding remedies is feasible, some structural support will be needed.

Organic silts, organic clays, and peat are highly compressible. Although these soils may have sufficient bearing capacity to support the embankment without failing in shear, excessive settlements are the concern. Remedies for neutralizing excessive settlement include preconsolidating soft clays by careful overloading, slow construction, or removal of the inadequate material. Analyses for preconsolidation measures require calculations for primary and secondary consolidation rates. The cost for delaying construction, until secondary consolidation is achieved, must be evaluated against the cost for removal and replacement.

The potential for failure exists when embankments are placed on thin layers of soft clays, particularly if the clay layers are inclined in an unfavorable orientation. The failure occurs by sliding horizontally or at the angle of the clay layer. The clay layer gains strength as it consolidates under construction and embankment loadings. If the imposed stresses increase faster than the consolidation, failure results. This type of failure occurs during or soon after construction for this reason. In this situation, construction and fill placement must proceed at a slower pace to allow the clay to consolidate. Also, lighter embankment material may be used or the embankment slopes could be flattened. Again, removal and replacement of the clay layer can also be a consideration.

Several types of slope failure are illustrated in Figure C.26.

Slope failure occurs whenever the available resisting forces are less than the activating forces causing instability. In effect, when the strength of the soil is less than the downslope force component of the soil weight and other applied loads, the result is slope movement.

An imbalance of the two countering forces results in a couple of ways: increasing load (driving force) or decreasing strength or resistance (resisting force). An increase in loading at the top of the slope can be brought about through the addition of a structure or by steepening the slope. Weakening of the slope can occur as a result of undercutting the toe of the slope or a rise of the water table under the slope.

Soil strength, particularly in cohesionless soils, is reduced by an increase in ground water (i.e., pore water) pressure. Ground water pressures are increased by raising the water table through excessive rainfall and snowmelt or seepage from underground springs and lakes.

Piping (internal erosion) and drawdown often cause slope failure on dam embankments. Rapid drawdown of a reservoir behind an embankment can cause an increase in the effective weight of the embankment, analogous to adding weight at the top of the slope. The term *piping* is used to describe the progressive removal of soil particles caused by percolating water (seepage) through an embankment dam.

Vibrations from earthquakes, blasting, and pile driving can cause densification of loose sands, silts, and some other highly compressible soils located below the ground water level, which increases the pore water pressure and correspondingly reduces the available soil shear strength. Cyclic stresses can also cause liquefication of loose uniform saturated sand layers.

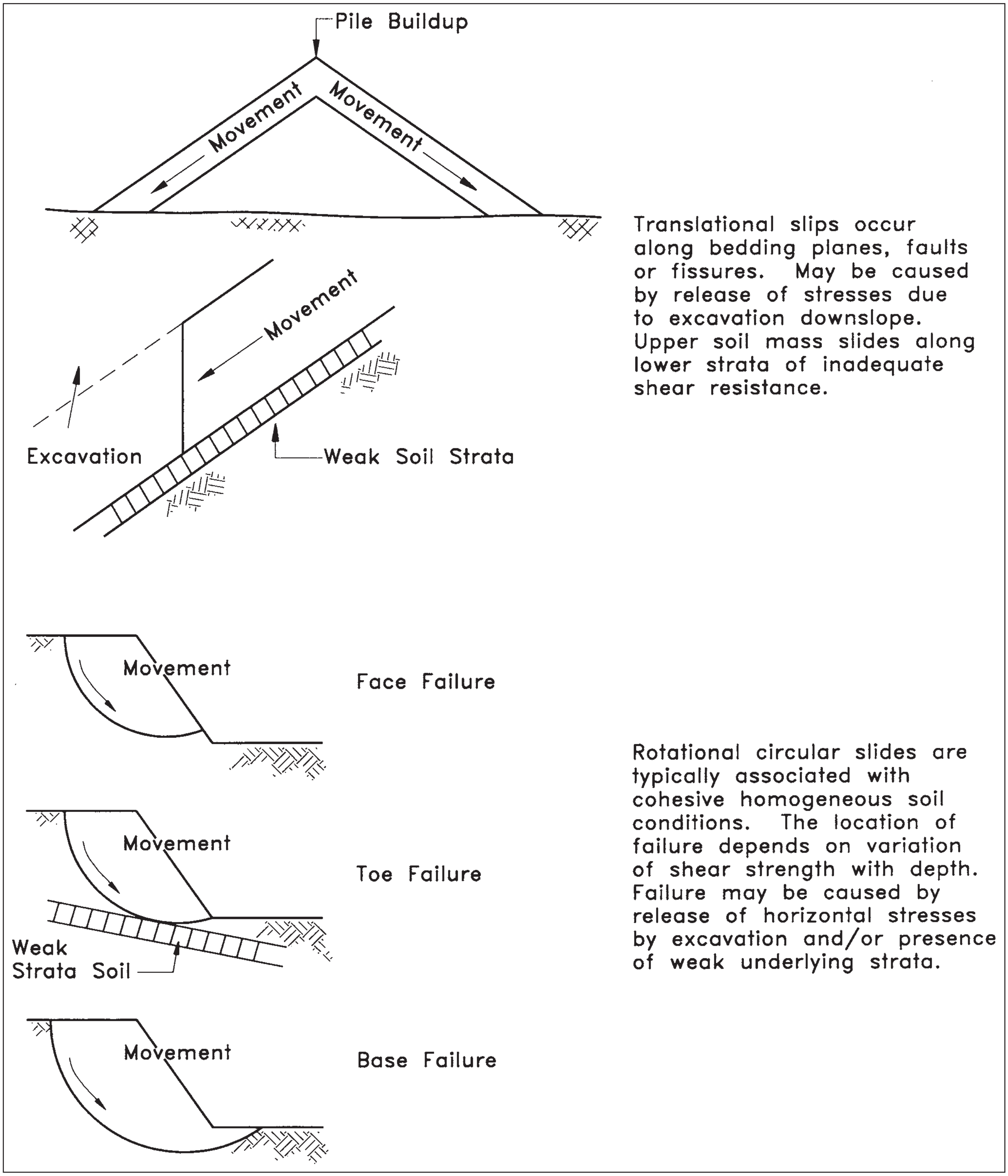


FIGURE C.26 Types of slope failures. (From Schroeder/Dickenson, *Soils in Construction,* 4th ed., copyright 1984. Reprinted by permission of Pearson Education, Inc. Upper Saddle River, NJ)

Natural processes such as weathering, leaching, creep, and mineralogical changes in soil and rock masses can reduce shear strength of the soil and result in slope movement.

Examples of two cut slope (shear) failures due to oversteepening are shown in Figure C.27.

SOIL COMPACTION

The stability of any structure founded on soil depends on the strength and stability of the soil itself. Engineering properties and characteristics of in situ soil can be markedly different than the same soil that has been excavated and used elsewhere. In some cases the existing soil in its natural state is not suitable as a foundation base, whereas it may be if properly recompacted or prepared. In other cases, excavated soil may not be suitable for any reuse beyond landscaping purposes. The land development engineer relies on the recommendations of a geotechnical expert on the strength and stability of a soil and what methods might be used for improving its performance. Methods for increasing soil strength include adding material or chemicals to the soil or increasing the density by controlled compaction. For many land development projects, the land development engineer is typically concerned with the following recurring situations:

- Bearing capacity and settlement potential of the existing soil to sustain the structure loads of buildings or pavement
- Bearing capacity and settlement potential of excavated soil that is reused on the site
- Slope stability of soil used in embankments
- Slope stability of soil in cut areas

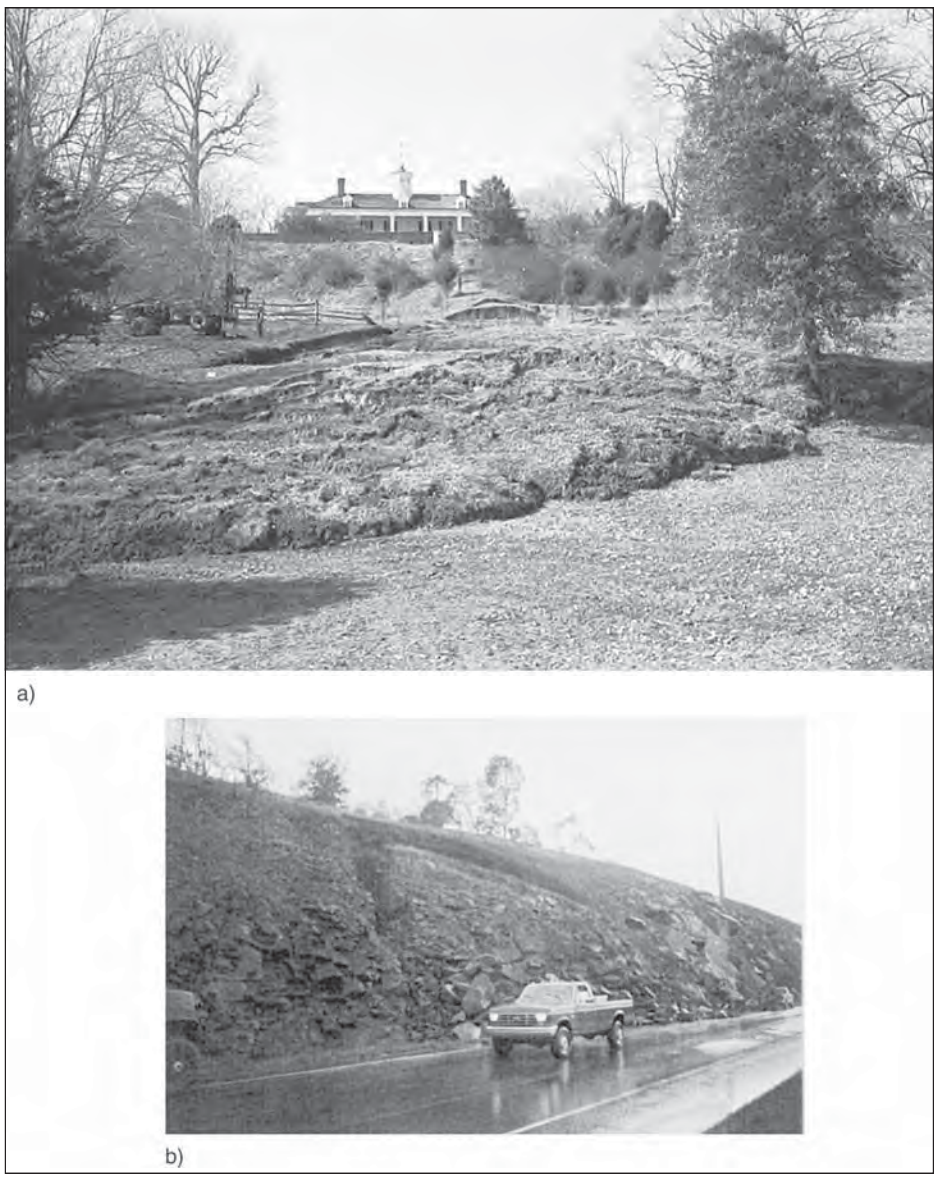


FIGURE C.27 Cut slope failures. (Photo courtesy of Paul G. Swanson)

The strength depends on the void ratio and the moisture content of silty and clayey soil. Compaction usually increases the strength characteristics of soil, decreases the settlement potential, and increases slope stability of embankments, by decreasing the void ratio, and increasing the density of the soil. Minimum compaction requirements are identified in the specifications or dictated by local standards. Usually, the geotechnical consultant recommends compaction requirements in the instances where none exist in local standards.

Compaction

Increasing soil density occurs by rearrangement of the soil particles, fracture of the grains or bonds between them, and then rearrangement. To do any of this requires energy and compactive effort. The amount of energy needed depends on the soil material and the method used to apply the energy. The intraparticle bonds of cohesive soils resist the compaction efforts. Increasing the water content to an optimum value decreases the cohesive resistance (molecular bonds) and, hence, increases the effects of the compaction efforts. Distortion and reorientation of the particles attain the density of such soils. Resistance to compactive efforts of cohesionless soils is due to the intergranular friction that is aided by capillary tension. Increased density in these soils is mostly through rearrangement of the particles. Again, increasing the moisture content may increase the effects of the compaction efforts by decreasing capillary tension.

The two most widely used standard laboratory tests to determine the maximum dry unit weight and optimum moisture content (OMC) of a soil are the standard Proctor test (ASTM D-698) and the modified Proctor test (ASTM D-1557).

The degree of compaction is measured relative to the maximum dry unit weight of the soil. Water added to the soil during compaction acts as a lubricant. The soil particles slip over each other and form a more dense arrangement. For a given soil and constant compaction energy, the dry unit weight increases as the moisture content increases up to a certain point. The increase in unit weight is the result of fitting more and more soil particles into the same volume—in effect, decreasing the void spaces. Beyond a certain moisture content, the unit weight of the soil begins to decrease due to the incompressibility of water. At this stage the moisture in the soil begins to occupy the space that could have been occupied by the soil particles. The moisture content, which maximizes the unit weight of the soil with a constant compaction effort, is referred to as the *optimum moisture content* (OMC). See Figure C.28.

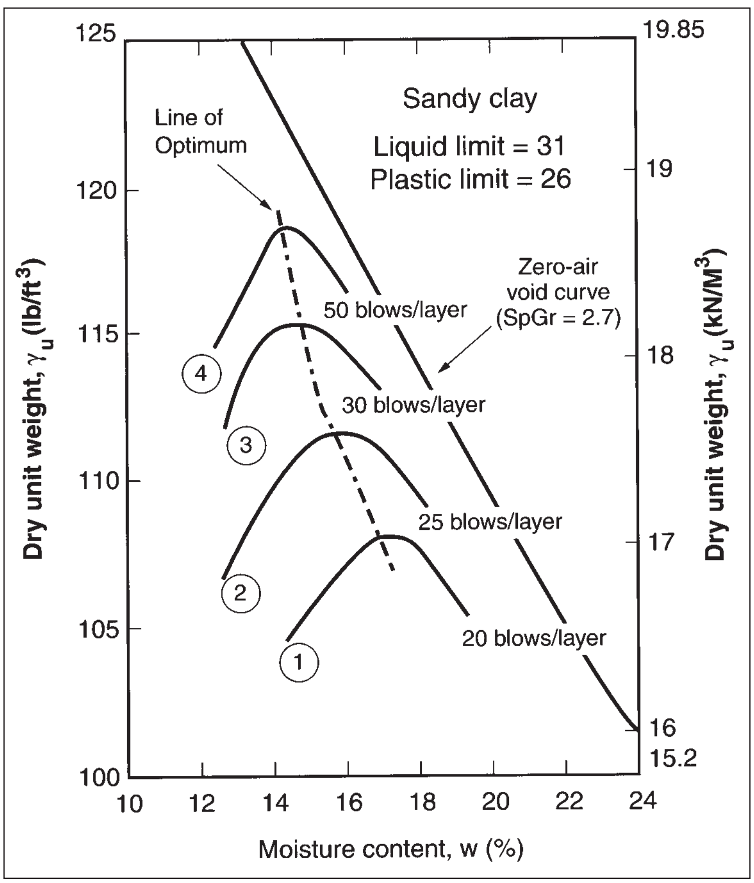


FIGURE C.28 Effect of compaction energy on dry unit weight. (From *Principles of Geotechnical Engineering,* 3rd ed., by B.M. Das © 1994. Reprinted with permission of Brooks/Cole, an imprint of the Wadsworth Group, a division of Thomson Learning)

Controlled Fill

For most soils, the soil will compact to its theoretically greatest density at an optimum moisture content (OMC). This OMC is around 8 percent for sands, 15 percent for silts, and 15 to 20 percent for clays. Fill areas that support structures must be placed under rigidly controlled conditions in order for the stability to be reasonably ensured. Typically, the controlled fill areas are identified on the plan sheets as "controlled fill—see note **" where "note **" refers to the compaction specification requirements relative to the maximum dry density and OMC of the fill material. Additionally, a maximum lift (layer) thickness will also be specified.

The specification for compaction might appear as "All fill shall be compacted to minimum 95% of the theoretical maximum density and within ±2% of the optimum moisture content in accordance with the specifications of ASTM D-698." Here, the theoretical maximum density is the density obtained from laboratory tests (i.e., standard Proctor). The 2 percent is the allowable tolerance of the moisture content from optimum. This allowable tolerance may vary somewhat depending on the compaction curve of the soil and the type of project. Specifying a percentage rather than a unit weight allows for the inherent variability of soils. This ensures a compactive effort in the field comparable to the laboratory test. The required density of the placed fill depends on the purpose of the compacted soil. Considerable cost savings can be realized by matching the density to the purpose. Table C.13 provides recommendations for compaction requirements.

Spreading a layer of soil to an appropriate thickness and using the proper equipment to compact the layer helps to control compaction during construction. When compaction of that layer is completed, another layer is spread and the equipment compacts the next layer. This process is repeated until the fill area is brought to the desired elevation. The thickness of the soil layers, also known as *lifts,* depends on the type of soil. Cohesive soils are typically placed in lifts of 6 to 8 inches. Lifts for well-graded gravel and sands are 10 to 12 inches. The practice of compacting soils in small uniform lifts helps maintain a uniform strength throughout the fill depth.

Controlling moisture content during construction is relatively easy for sandy soils and those that are drier than OMC. Dry soils are sprinkled with water before or as the soil is being compacted. The soil needs to be thoroughly mixed for even distribution of moisture. Soils wetter than the OMC can be spread to dry or mixed with other, drier suitable soils before being placed. In general, plastic (clayey) soils are more sensitive to moisture content and must be compacted within a smaller range of the OMC to attain maximum density.

Specifications for controlled fill require that certain materials be excluded. These materials reduce the ultimate attainable strength or exacerbate settlement problems. Materials such as soils with excessive organic contents (more than 10 percent), trees, and vegetation cause excessive localized settlements after degradation. Large boulders, cobbles, flat shale fragments, and construction debris also adversely affect compaction.

Methods for Monitoring Field Compaction

Specifications typically dictate the desired results for compaction in order to ensure a result that will have a reliable performance. Part of the assurance, dictated by specifications, involves the field testing of in-place fill. Several standard methods exist for field testing the in-place soil to determine whether the compaction efforts are producing specification quality.

The sand cone test (ASTM D-1556) and the rubber balloon test (ASTM D-2167) use material of known density to fill a small-excavated hole in the compacted area. In the sand cone test, the excavated hole is filled with sand. The balloon test inserts a balloon into the hole and fills it with water. In either case, the volume of the hole can be determined from the amount of sand or water used to fill the excavated hole. The excavated material is then weighed, oven dried, and weighed again to determine the water content. The results are then compared to the specification.

Another method of determining compaction uses a nuclear density gauge to measure the density and water content. The gauge consists of a radiation source, radiation detector, and counter. The gauge emits radiation into the soil and the reflected emissions are counted. Knowing how the density and water reflect the emissions determines the unit weight and moisture content of the soil. The advantages of this method are that the test does not require a hole and that the results are available immediately.

An example illustrates how data from the sand cone test measures compaction.

EXAMPLE

The test results from a sand cone test are shown in Table C.14. Determine whether the compaction meets the required specifications. The project specifications require compaction to 95 percent of the maximum dry density (MDD) with moisture content to be within 2 percent of OMC as determined by the Proctor test. Laboratory test results indicate the MDD as 119.5 lb/ft^3 at an OMC of 13.0 percent. At the project site, two tests were made. The sand used in the sand cone test had a density of 114.5 lb/ft^3.

Specification requirements for this soil:

Dry density $\lambda_d = 0.95 \times 119.5 = 113.5$ lb/ft^3

Moisture content, w: min. 11.0%, max. 15.0%

For test #1:

$$\text{Vol}_1 = \frac{9.05\ \text{lb}}{114.5\ \text{lb/ft}^3} = 0.079\ \text{ft}^3$$

$$w_1 = \frac{9.66 - 8.75}{8.75} \times 100 = 10.4\% \qquad \text{(C.14)}$$

$$\gamma_{d1} = \frac{8.75\ \text{lb}}{0.079\ \text{ft}^3} = 110.8\ \text{lb/ft}^3$$

TABLE C.13 Compaction Requirements*

Fill Utilized for:	Required Density % of Standard Proctor	Tolerable Range of Moisture about Optimum, %	Maximum Permissible Lift Thickness, Compacted (in.)	Special Requirements
Support of structure	95	–2 to +2	12	Fill should be uniform. Blending or processing of borrow may be required. For plastic clays, investigate expansion under saturation for various compaction moisture and densities of loads equal to those applied by structure, to determine condition to minimum expansion. Clays that show expensive tendencies generally should be compacted at or above optimum moisture to a density consistent with strength and incompressibility required of the fill.
Lining for canal or small reservoir	90	–2 to +2	6	For thick linings, GW-GC, GC, SC are preferable for stability and to resist erosive forces. Single-size silty sands with PI less than 5 generally are not suitable. Remove fragments larger than 6 inches before compaction.
Earth dam greater than 50 ft high	95	–1 to +2	12(+)	Utilize least pervious materials as central core and coarsest materials in outer shells. Core should be free of lenses, pockets, or layers of pervious material and successive lifts well bonded to each other. Amounts of oversize exceeding 1% of total material should be removed from the borrow prior to arrival on the embankment.
Earth dam less than 50 ft high	92	–1 to +3	12(+)	In small dams that lack elaborate zoning, materials that are the most vulnerable to cracking and piping should be compacted to 98% density at moisture content from optimum to 3% in excess of optimum.
Support of pavements: Highways	95% within top 2.0 ft; 90% top below 2.0 ft	–2 to +2	8(+)	Place coarsest borrow materials at top of fill. Investigate expansion of plastic clays placed near pavement subgrade to determine compaction moisture and density that will minimize expansion and provide required soaked CBR values.
Backfill surrounding structure	90	–2 to +2	8(+)	Where backfill is to be drained, provide pervious coarse-grained soils. For low walls, do not permit heavy rolling compaction equipment to operate closer to the wall than a distance equal to about ⅔ the unbalanced height of fill at any time. For highwalls or walls of special design, evaluate the surcharge produced by heavy compaction equipment by the methods of Chapter 3 and specify safe distances back of the wall for its operations.
Backfill in pipe or utility trenches	90	–2 to +2	8(+)	Material excavated from trench generally is suitable for backfill if it does not contain organic matter or refuse. If backfill is fine-grained, a cradle for the pipe is formed in natural soil and backfill placed by tamping to provide the proper bedding. Where free-draining sand and gravel are utilized, the trench bottom may be finished flat and the granular material placed saturated under and around the pipe and compacted by vibration.

TABLE C.13 (*Continued*)

Fill Utilized for:	Required Density % of Standard Proctor	Tolerable Range of Moisture about Optimum, %	Maximum Permissible Lift Thickness, Compacted (in.)	Special Requirements
Drainage blanket or filter	90	Thoroughly wetted	8	Ordinarily vibratory compaction equipment is utilized. Blending of materials may be required for homogeneity. Segregation must be prevented in placing and compaction. For compaction adjacent to and above drainage pipe, use hand tamping or light traveling vibrators.
Subgrade of excavation for structure	95	–2 to +2	—	For uniform bearing or to break up pockets of frost-susceptible material, scarify the upper 8 to 12 inches of the subgrade, dry or moisten as necessary and recompact. Certain materials, such as heavily preconsolidated clays that will not benefit by compaction, or saturated silts and silty fine sands that become quick during compaction, should be blanketed with a working mat of lean concrete or coarse-grained material to prevent disturbance or softening. Depending on foundation conditions revealed in exploration, a substantial thickness of loose soils may have to be removed below subgrade and recompacted, or compacted in place by vibration or pile driving.
Rock fill		Thoroughly wetted	2 to 3 ft	For fill containing sizes no larger than ft, place in layers not exceeding 24 inches, thoroughly wetted and compacted by travel or heavy crawler tractors in spreading. Material with sizes up to 2 feet may be placed in 3-feet lifts. Placing should be such that the maximum size of rock increases toward the outer slopes. Rocks larger than 1 cubic yard in volume should be embedded on the slope.

Notes:
1. Density and moisture content refer to standard Proctor test values (ASTM D 698).
2. Generally, a fill compacted dry of OMC will have higher strength and a lower compressibility even after saturation.
3. Compaction of coarse-grained, granular soil is not sensitive to moisture content so long as bulking moisture is avoided. Where practicable, they should be placed saturated and compacted by vibratory methods.
*NAVFAC DM7.2.

For test #2:

$$\mathrm{Vol}_2 = \frac{7.25\ \mathrm{lb}}{114.5\ \mathrm{lb/ft^3}} = 0.063\ \mathrm{ft^3}$$

$$w_2 = \frac{8.45 - 7.41}{7.41} \times 100 = 14.0\% \qquad \text{(C.15)}$$

$$\gamma_{d2} = \frac{7.41\ \mathrm{lb}}{0.063\ \mathrm{ft^3}} = 117.6\ \mathrm{lb/ft^3}$$

The results show that compaction in the area of test #1 does not meet specifications. The moisture content is less than 2 percent of optimum and the unit weight is less than 95 percent MDD. Test #2 meets the compaction requirements.

Compaction Equipment

In the laboratory, soil type and moisture content are the main factors affecting maximum density. However, in the field, other factors, which cannot be as rigidly controlled as in the laboratory, affect the actual degree of compaction. Such factors as the thickness of the lift, intensity of pressure

TABLE C.14 Sand Cone Test Results

	Wet Wt.	Dry Wt.	Sand Wt.
Hole #1	9.66 lb	8.75 lb	9.05 lb
Hole #2	8.45 lb	7.41 lb	7.25 lb

applied, area of applied pressure, and number of times pressure is applied all determine the ultimate unit weight attained at the project site. Effective compaction is attained by applying a large enough force to reorient and densify the soil particles, however, too large a force can cause the soil mass itself to be sheared.

Rollers are the primary method for field compaction. Rollers compact the soil by expelling air from the voids and forcing the soil particles into a compact arrangement. Common rollers are smooth drum roller, pneumatic rubber-tired roller, sheepsfoot roller, and vibratory roller. Figure C.29 shows a vibratory smooth drum and sheepsfoot roller working in tandem to compact an engineered fill. Rollers are available in various sizes and weights. Roller weights can be varied somewhat by filling the drums or body with fluid or sand. The type of roller used depends on soil characteristics, maneuvering space, intended function of the soil, and economic considerations. Table C.15 summarizes commonly used compaction equipment and methods.

GROUND IMPROVEMENT METHODS

Numerous ground improvement techniques have been developed and/or perfected in the last half century. Geotechnical engineers have found new ways to compensate for Mother Nature's less than desirable subsurface conditions and for continued redevelopment of urban areas. This rapid growth and use of ground improvement techniques has been fueled by the increasing need to develop marginal land and develop cost-effective solutions for land development and redevelopment applications.

Some of the ground improvement techniques available today include:

- Undercut and replace
- Vibro compaction/replacement
- Dynamic compaction
- Wick/band drains
- Lime and cement stabilization
- Geosynthetics

Ground improvement techniques described herein have been successfully employed globally to facilitate construction on otherwise undesirable properties. These techniques are briefly discussed so land development engineers can offer potential solutions to clients who would like to develop problematic building sites.

Vibro Compaction/Replacement

Vibro compaction/replacement has been used for over 50 years to reduce settlement and improve bearing capacity on noncohesive soils. The addition of stone through special vibro-replacement equipment allows improvement of weak ground and poorly controlled man-made fills. Vibro-techniques have been successfully used on housing projects, warehouses, and light industrial structures (Moseley & Priebe: Ground Improvement, 1993). See Figure C.30.

Dynamic Compaction

The use of dynamic compaction, occasionally referred to as *ground pounding*, has increased considerably in the past 25 years and is a widely accepted technique for improving weak soils, rubble fills, solid waste, collapsible soils, and liquefiable soils. The simplicity and economic benefits of dynamic compaction have made it an attractive alternative to preloading, vibro-techniques, and deep foundation systems.

Dynamic compaction involves the systematic dropping of large weights onto the ground surface to compress and consolidate weak or soft soil and rubble material. Heavy weights of 5 to 20 tons falling from heights of 30 to 85 feet are typically used to improve the bearing capacity and reduce differential settlement of the underlying ground to depths of 30 feet or more. (Mayne, et al., 1984).

Dynamic compaction is most widely used to improve primarily sandy materials and granular fills, but it has also been used to improve sites containing fine-grained soils. The

Figure C.29 Vibratory and sheepsfoot rollers. (Photo: Frost)

TABLE C.15 Compaction Equipment and Methods

REQUIREMENTS FOR COMPACTION OF 95 TO 100% STANDARD PROCTOR MAXIMUM DENSITY

Equipment Type	Applicability	Compacted Lift Thickness, inches	Passes or Coverages	Dimensions and Weight of Equipment	Possible Variations in Equipment
Sheepsfoot rollers	For fine-grained soils or dirty coarse-grained soils with more than 20% passing the No. 200 sieve. Not suitable for clean coarse-grained soils. Particularly appropriate for compaction of impervious zone for earth dam or linings where bonding of lifts is important.	6	4–6 passes for fine-grained soil; 6–8 passes for coarse-grained soil	Soil type / Foot contact area, in^2 / Foot contact pressures, lb/in^2: Fine-grained soil $PI > 30$: 5–12; 250–500 Fine-grained soil $PI < 30$: 7–14; 200–400 Coarse-grained soil: 10–14; 150–250 Efficient compaction of soils wet of optimum requires less contact pressures than the same soils at lower moisture contents.	For earth dam, highway, and airfield work, drum of 60-in. diameter, loaded to 1.5–3 ton per lineal foot of drum, is generally utilized. For smaller projects 40-in.-diameter drum, loaded to 0.75–1.75 tons per lineal foot of drum is used. Foot contact pressure should be regulated to avoid shearing the soil on the third or fourth pass.
Rubber tire rollers	For clean, coarse-grained soils with 4–8% passing the No. 200 sieve. For fine-grained soils or well-graded, dirty, coarse-grained soils with more than 8% passing the No. 200 sieve.	10 6–8	3–5 coverages 4–6 coverages	Tire inflation pressures of 60–80 lb/in^2 for clean granular material or base course and subgrade compaction. Wheel load 18,000–25,000 lb. Tire inflation pressure in excess of 65 lb/in^2 for fine-grained soils of high plasticity. For uniform clean sands or silty fine sands, use large-size tires with pressures of 40–50 lb/in^2.	Wide variety of rubber-tire compaction equipment is available. For cohesive soils, light wheel loads, such as provided by wobble-wheel equipment, may be substituted for heavy-wheel load if lift thickness is decreased. For cohesionless soils, large-size tires are desirable to avoid shear and rutting.

Smooth wheel rollers	Appropriate for subgrade or base course compaction of well-graded sand-gravel mixtures.	8–12	4 coverages	Tandem-type rollers for base course or subgrade compaction, 10–15 ton weight, 300–500 lb per lineal inch of width of rear roller	3-wheel rollers obtainable in wide range of sizes. 2-wheel tandem rollers are available in the range of 1- to 20-ton weight. 3-axle tandem rollers are generally used in the range of 10- to 20-ton weight. Very heavy rollers are used for proof rolling of subgrade or base course.
	May be used for fine-grained soils other than in earth dams. Not suitable for clean well-graded sands or silty uniform sands.	6–8	6 coverages	3-wheel roller for compaction of fine-grained soil; weights from 5–6 tons for materials of low plasticity to 10 tons for materials of high plasticity	
Vibrating baseplate compactors	For coarse-grained soils with less than about 12% passing the No. 200 sieve. Best suited for materials with 4–8% passing No. 200 sieve, placed thoroughly wet.	8–10	3 coverages	Single pads or plates should weigh no less than 200 lb. May be used in tandem where working space is available. For clean coarse-grained soil, vibration frequency should be no less than 1600 cycles/min.	Vibrating pads or plates are available, hand-propelled or self-propelled, single or in gangs, with width of coverage from 1½ to 15 ft. Various types of vibrating-drum equipment should be considered for compaction in large areas.
Crawler tractor	Best suited for coarse-grained soils with less than 4–8% passing No. 200 sieve, placed thoroughly wet.	10–12	3–4 coverages	No smaller than D8 tractor with blade, 34,500-lb weight, for high compaction	Tractor weights up to 60,000 lb.
Power tamper or rammer	For difficult access, trench backfill. Suitable for all inorganic soils.	4–6 in. for silt or clay, 6 in. for coarse-grained soils	2 coverages	30-lb minimum weight. Considerable range is tolerable, depending on materials and conditions.	Weights up to 250 lb; for diameter 4–10 in.

FIGURE C.30 Vibro-replacement ground improvement method using stone column.

degree of improvement varies with soil type and ground water depth.

Poor subsurface soil conditions including sites proposed for office buildings, warehouses, town houses, highways, airports, and industrial sites have been successfully improved using dynamic compaction. See Figure C.31.

Wick/Band Drains

Wick/band drains are used to accelerate the consolidation of low-permeability fine-grained soils. Discussion of time rate consolidation earlier in this chapter indicated that settlements of clayey soils were dependent on the dissipation of pore water out of the void spaces. The faster the water can be squeezed out of the soil layer, the faster the settlement will occur.

The installation of wick or band drains vertically into the compressible layer on a predetermined spacing reduces the flowpath length of the water and speeds up consolidation.

Wick/band drain installation is usually associated with preloading or large fill projects where settlement times must be shortened to accommodate future construction or civil projects such as highway approaches to bridge structures and airport runways. See Figure C.32.

Lime and Cement Stabilization

Lime and cement stabilization is used where poor near-surface soil conditions can be economically altered through the introduction of lime or cement. Soil stabilization with admixtures has been used extensively in the highway construction field for many years.

Soil-Cement. This term, commonly adopted from cement stabilization research refers to a mixture of Type I Portland cement and soil. The use of soil-cement has proven to be very successful for improving sandy and silty subgrade soils for support of airfields, roadways, and large parking lots.

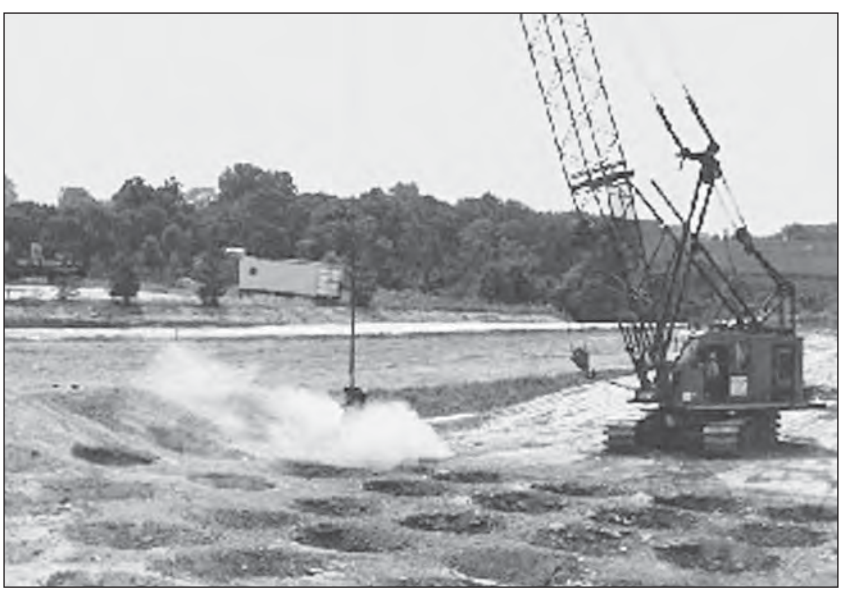


FIGURE C.31 Photo of dynamic compaction. (Courtesy of Terasystems, Inc.)

FIGURE C.32 Wick drain installation.

The addition of between 3 and 8 percent cement by weight is typical, depending on the strength characteristics desired.

Lime Stabilization. This is also referred to as *lime modification* when smaller amounts of lime are utilized in an effective method to alter the undesirable characteristics of highly plastic clayey soils when used for subgrade support. Generally, stabilization techniques with hydrated lime are likened to those with cement. The difference, however, is that lime is more effective with fine-grained soils having plasticity. The addition of between 4 and 6 percent of hydrated lime by weight is common for subgrade improvement. See Figure C.33.

Geosynthetics

Available since the 1960s, geosynthetics have exploded within the engineering/construction market over the last 20 years. Applications for geosynthetics are rapidly expanding and will likely continue to gain popularity as cost-effective alternatives to traditional construction methods.

This industry includes product categories such as geogrids, geotextiles, geocomposites, geonets, and geomembranes, all of which serve distinct and varied purposes. See Figure C.34.

FIGURE C.33 Lime stabilization.

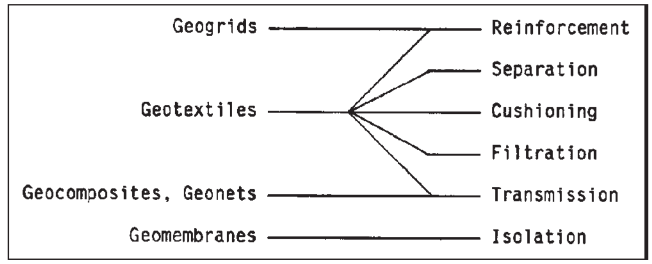


FIGURE C.34 Functions of major types of geosynthetics. (Fluet, 1988)

Reinforcement. By adding tensile strength to the soil, geogrids and geotextiles can support horizontal loads like those found in MSE walls and vertical loads like those experienced beneath wheeled traffic loads. See Figure C.35.

Separation. Keeping two different materials apart is accomplished through the use of geotextiles. See Figure C.36.

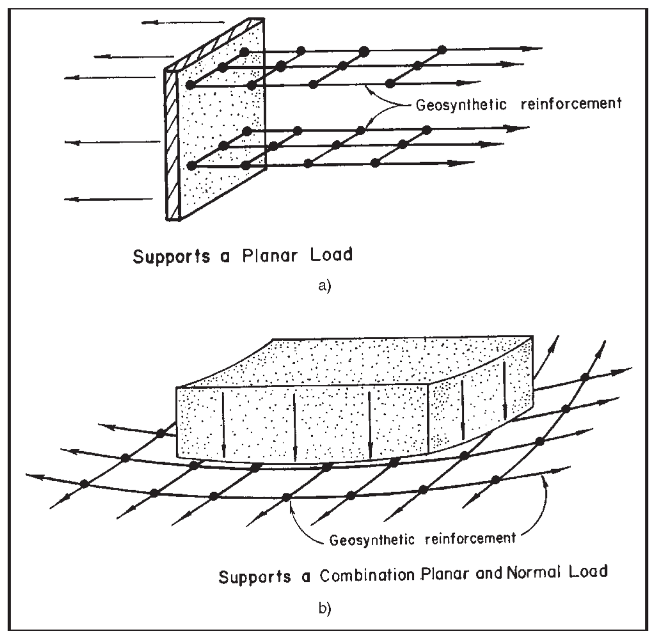


FIGURE C.35 Reinforcement function: (*a*) tensile member; (*b*) tensioned member. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

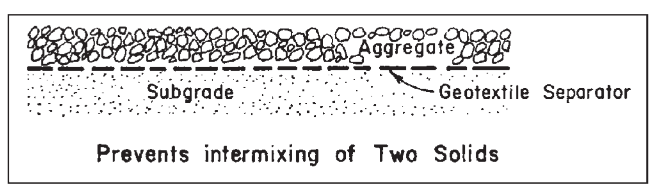


FIGURE C.36 Separation function. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

Cushioning. Cushioning provides separation and absorbs impact or abrasive action that could damage critical membranes. This is common in ponds that are lined but require ballast to hold down the liner. See Figure C.37.

Filtration. Filtration allows water to pass unrestricted while retaining soil or other materials. This is common for trench drains and erosion control measures. See Figure C.38.

Transmission. Drainage allows water or other fluids to move along or within the geosynthetics. Geocomposites/geonets are used for a variety of applications, commonly including drainage behind walls and wick drains. See Figure C.39.

Isolation. This can refer to the retention of one fluid or the separation of two fluids. Geomembranes in landfills and pond liners are examples of isolation products. See Figure C.40. Common applications for isolation products include:

- Roadway subgrade stabilization
- Asphalt overlay support
- MSE wall reinforcement
- Filters and drains for roadways, walls, and trench drains
- Erosion control and silt fences
- Consolidation drains
- Impermeable liners
- Slope stability

SUMMARY

It is paramount that the land design team be aware of the nature of subsurface conditions at the site. These conditions not only have an impact on how and where specific features are constructed, but also affect the cost to develop the site.

During the early stages of the design, subsurface information obtained from existing data is often adequate to make preliminary decisions about development of the site. This information is also useful in the planning of the detailed subsurface investigation. Results from the preliminary (or desktop) investigation produce the information needed to make decisions on whether to proceed with the project or abandon the site and seek another site altogether. If the project proceeds, additional subsurface exploration is likely to be required for design and construction purposes.

The land development engineer must rely on the expertise of the geotechnical engineer for recommendations pertaining to slopes in cut and fill areas, acceptability of soils for dams and infiltration facilities, bearing capacity for foundations and pavement designs, and the identification of problem soil conditions that would affect the proposed development program.

LIST OF SELECTED ASTM TESTING METHODS

Listed here are selected ASTM test methods that are commonly used during a geotechnical investigation. Detailed procedures for these and other tests can be found on the ASTM website (www.ASTM.org).

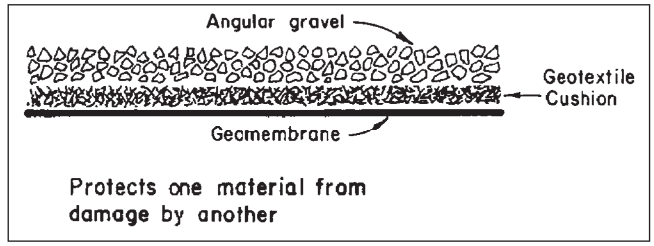


FIGURE C.37 Cushioning function. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

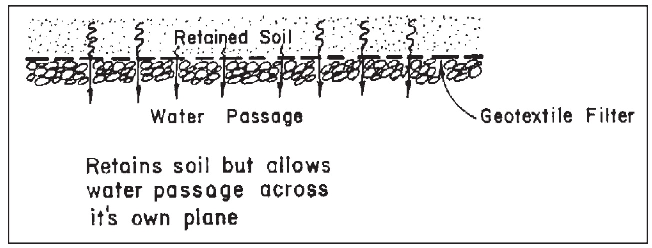


FIGURE C.38 Filtration function. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

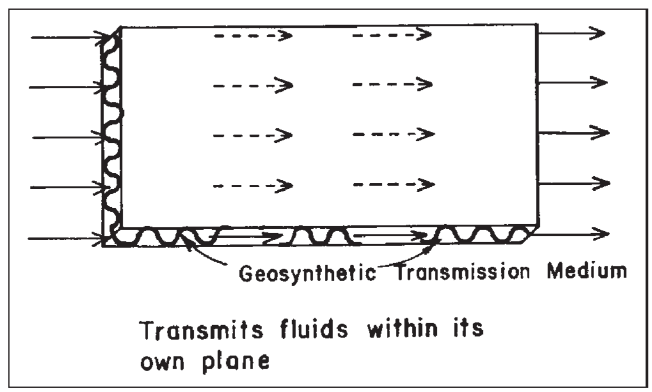


FIGURE C.39 Transmission function. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

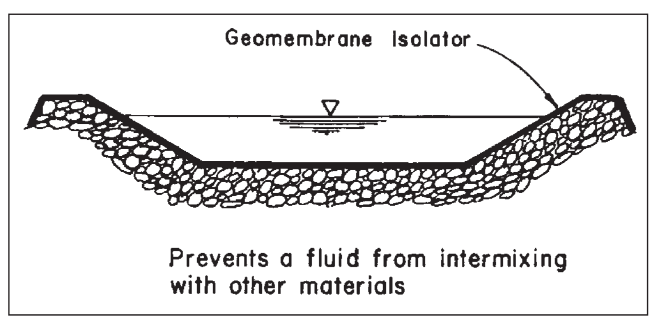


FIGURE C.40 Isolation function. (Fluet, 1988; from *Geosynthetics for Soil Improvement,* by R.D. Holtz, ASCE 1988. Reprinted with permission from American Society of Engineers)

ASTM D-422 Particle-Size Analysis of Soils

ASTM D-423 Standard Test for Liquid Limit of Soils

ASTM D-424 Standard Test Method for Plastic Limit and Plasticity index of Soils

ASTM D-698 Standard Test for Moisture-Density Relations of Soils and Soil Aggregate Mixtures Using 5.5 lb. Rammer and 12 in. Drop

ASTM D-1140 Standard Test Method for Amount of Material in Soils Finer Than the No. 200 (75 μm) Sieve

ASTM D-1452 Standard Practice for Soil Investigation and Sampling by Auger Boring

ASTM D-1556 Standard Test Method for Density of Soil in Place by the Sand-Cone Method

ASTM D-1557 Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10 lb Rammer and 18 in. Drop

ASTM D-1587 Standard Practice for Thin-Walled Tube Sampling of Soils for Geotechnical Purposes

ASTM D-1883 Bearing Ratio of Laboratory-Compacted Soils

ASTM D-2166 Unconfined Compressive Strength of Cohesive Soil

ASTM D-2167 Density of Soil in Place by the Rubber Balloon Method

ASTM D-2487 Classification of Soils for Engineering Purposes

ASTM D-2434 Standard Test Method for Permeability of Granular Soils (Constant Head)

ASTM D-2435 Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading

ASTM D-2573 Standard Test Method for Field Vane Shear Test in Cohesive Soil

ASTM D-2850 Unconsolidated, Undrained Strength of Cohesive Soils in Triaxial Compression

ASTM D-3080 Direct Shear Test of Soils Under Consolidated Drained Conditions

ASTM D-3282 Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes

ASTM D-6151 Standard Practice for Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling

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APPENDIX D

WASTEWATER TREATMENT

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ON-SITE SYSTEMS

General Information

The most desirable means of managing the sewage flow from a home or community is through a central system where wastewater is conveyed to a community-owned facility for treatment and disposal. However, many homes will not be located where a central system is available. Also, when the lot size becomes greater than about ¾ acre, the per-unit cost of installing a collecting sewer system may become prohibitive, limiting options for wastewater management to on-site systems. Until very recently, a septic tank/drain field system was the only satisfactory on-site alternatives available to the design engineer or homeowner. The regulations for on-site drain fields, which have become more stringent in recent years, now clearly define the types of soils and the depths to the water table that are satisfactory for the design and placement of septic tank drain fields. Thus, local soil conditions may make many locations unsuitable for this method of wastewater management. In instances where the soil is found to be unsuitable or the water table is too high for a septic tank/drain field system, the design engineer has other options available that may make it possible to locate a reliable on-site system on a lot. Design procedures for several alternative systems are presented in this chapter.

The requirement for an on-site wastewater management system need not detract from the development potential of a particular site. An on-site facility may mean a larger lot size; however, many homes and businesses have been satisfactorily served by on-site systems for years. More than 25 percent of the homes in the United States rely on on-site systems and about 0.5 million new homes are being added to this number each year. It has been estimated that about one-third of the land in the United States is suitable for on-site systems employing absorption fields.

Pressure for development often occurs in land areas that are not the most suitable for absorption systems. Land availability, together with higher land costs, means that lot size continues to decrease, placing greater restrictions on areas suitable for an on-site absorption field. Denser housing, environmental awareness about ground and surface water pollution, and a better understanding of design requirements have caused and will continue to cause public health officials to impose additional conditions on the design and placement of absorption fields.

The high failure rate for older on-site systems that were located in unsuitable soil has contributed to a low opinion of the technology by some prospective homeowners. Septic tank failures occur because of poor design, construction, and maintenance. A properly designed, constructed, and maintained system offers an affordable, reliable, and environmentally sound means of providing on-site wastewater management. The absence of central sewerage with downstream municipal treatment works need not always reduce the potential of a proposed site for development.

In fact, the green building movement has emphasized the value of on-site wastewater treatment installations as both a conservation measure and an environmentally and technically sound approach to meeting an infrastructure requirement. Most green building rating systems that extend credits for wastewater treatment take a two-pronged approach: (1) reduce building water consumption and therefore sewage outputs through appropriate fixture selection and graywater/blackwater reuse strategies and (2) employ on-site wastewater treatment processes that meet tertiary water quality standards (for specific requirements, refer to the U.S. Green Building Council's LEED system, Water Efficiency Credit 2). While it is rare for the civil engineer to influence the building fixture selection, it is still important to understand this component of the building program so as to accurately project sewage loads (see Chapter 24) and make appropriate collection and treatment recommendations. If on-site wastewater treatment is required (motivated through necessity or green building goals), an experienced civil engineer who specializes in wastewater treatment is the best resource in terms of providing feasible system options—mechanical or natural—that will meet both regulatory and owner requirements (i.e., green building goals).

The performance of an on-site system depends on several local geographic and geologic conditions including the average annual temperature, the depth to ground water, the distance to bedrock, the type and degree of weathering of the bedrock, the type and depth of soil, and the annual rainfall. The material presented herein is only a guide to sound design practice. This is a field of rapidly developing technology. The alternatives included herein represent the principal technologies in use. The engineer should have a broad knowledge of the acceptable alternatives for the local geographic and political area. The EPA National Small Flow Clearinghouse (see Table D.5) is a source of current data covering new technology.

Regulations for on-site systems are controlled at the state and local government level and may vary significantly between two adjacent political boundaries. A builder or developer should have an engineer conduct an investigation to determine the on-site technology that is appropriate for the specific land area before proceeding with plans leading to construction. The selected alternative may impact the development plan in the placement and size of lots, building locations, and design of other infrastructure systems.

Septic Tanks

The septic tank and associated absorption field has been the most widely used on-site wastewater management system in the United States for many years. A septic tank is a buried, watertight receptacle designed to receive wastewater flow. The tank has no moving parts but is sized and constructed to remove and retain the settleable and floatable material in the incoming flow. The solids removed in the septic tank are mostly organic matter that will consolidate and partly decompose. While the effluent is largely devoid of settleable and floating solids, it is septic, carries a significant amount of suspended and dissolved organics, and requires further treatment. Septic tanks for single-family homes are generally purchased from a local precast concrete firm that will deliver and set the tank on a prepared base. The design provided will normally comply with state and local codes. Precast tanks are preferred because they are normally well constructed and watertight. In areas where precast tanks are not available, concrete or masonry tanks are constructed in place. Metal tanks that have been properly coated to retard corrosion are also generally acceptable. Plastic and fiberglass tanks are also available and offer long-life service.

TABLE D.1 Septic Tank Volumes

Number of Bedrooms	Septic Tank Volume (gal)
1	750*
2	750*
3	1000
4	1200
5	1425
6	1650
7	1875
8	2100

*Many states have established 1000 gal or more as the minimum size.
(U.S. EPA, 2002.)

Design. The design of a septic tank should provide 24-hour flow retention plus maximum sludge and scum storage volume. This size is normally based on the number of bedrooms to be served. While the typical per-person contribution of wastewater flow is about 45 gallons per day (gpd), a flow rate of 75 gpd is generally used to provide a factor of safety in the design of the system. It is further assumed in the design of septic tank systems that there are two people per bedroom in a dwelling. Thus, the daily design flow for a two-bedroom dwelling is 300 gpd. When allowance is made for sludge and scum storage, a 750-gallon tank is needed for a two-bedroom home. The Uniform Plumbing Code recommends the tank volumes shown in Table D.1, which are equal to or greater than those required under the regulations of the Federal Housing Authority and the U.S. Public Health Service. Larger tanks may be needed for industrial or commercial flows or for serving a cluster of homes. The volume of the septic tank for this type of service should be at least 1.5 times the average daily flow. A utility or an equivalent organization should maintain tanks serving more than one home.

The inlet and outlet should be designed to still the incoming flow velocity, trap the scum layer, and minimize scour of the accumulated sludge into the effluent. Some suppliers of precast units may provide tanks having baffles placed to the proper depth across the tank at both the inlet and the outlet ends of the tank. Most tanks are supplied without baffles, and the installing plumber uses cast-iron or PVC tees to provide the required venting of gases and trapping of solids and scum. Figure D.1 shows the design of a typical tank outlet.

The outlet tee is normally 4 inches in diameter, but the vertical stem of the tee may be increased to 6 inches to reduce effluent rising velocity and thus reduce the potential

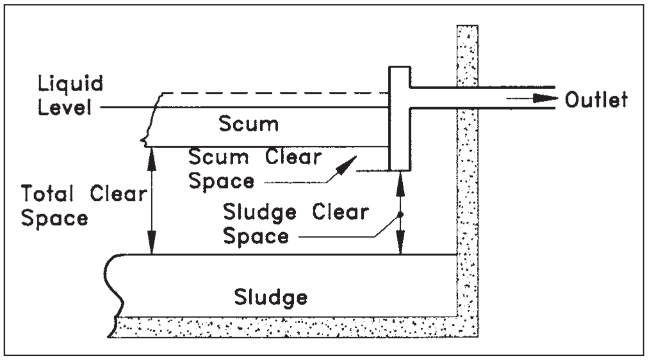

Figure D.1 Septic tank outlet design. (U.S. EPA, 2002)

for solids to be scoured into the effluent. The tee should project 12 percent of the liquid depth above and 24 percent of the liquid depth below the liquid level. Some local jurisdictions recommend that these projections be increased 50 percent for tanks serving homes having garbage grinders. It is also recommended that the septic tank volume be increased 250 gallons where a garbage grinder is installed on the system. The normal liquid depth in a tank is about 4 feet, with a 1-foot clear space above the liquid. Septic tank systems serving sources other than domestic homes may require pretreatment of the flow ahead of the tank. Flow from a restaurant should always pass through a grease trap ahead of the tank. Flow from some industrial establishments may require grit removal and/or screening ahead of the tank.

The septic tank must provide sufficient sludge storage. The accumulation of sludge depends primarily on temperature. If the influent to the tank has been screened to eliminate inert material, the organic solids should decompose into water and gases. In warm climates, where the tank contents are warm throughout the year, considerable decomposition will occur, with a corresponding decrease in solids accumulation. However, very little decomposition will occur at locations where the temperature of the tank contents drops during the winter months. Normally a septic tank should be checked every two years and should be cleaned when the sludge accumulation reaches to within 8 inches of the bottom of the outlet pipe. After accumulating a few years of record, the frequency of checking can be adjusted to the specific need. It is important to clean the tank before the sludge level reaches the outlet pipe entrance to prevent washout of solids from the tank. A manhole is located at both ends of the tank for inspection and cleaning.

The tank should be constructed to permit venting back through the influent piping and house plumbing to the roof vent.

Placement Considerations. Locate the septic tank in an area where vehicles will not cross or park on top of it. The tank should be placed such that the top is about 6 inches below grade to discourage entry by unauthorized persons and yet not be so deep as to present a problem at inspection and cleaning time.

The tank should be located to allow gravity flow from the source into the tank if possible. At locations where this is not possible, a duplex grinder pump is used to lift the flow from the building sewer to the septic tank.

Trees should not be planted near the tank because of the potential for root damage.

Operation and Maintenance Requirements. A properly installed and maintained septic tank should last for many years. Have a qualified septage-hauling firm check the tank for solids level every two years until evidence shows that a less frequent schedule is satisfactory. Check with the local health official for a list of qualified firms. Qualified firms are licensed by most localities.

If possible, pump the tank in late spring to allow stabilization to start during the warmer summer months. Some officials recommend that a small amount of solids be left in the tank to seed and buffer the new sludge. The tank should not be washed when it is cleaned. All that is needed is to pump the contents.

There is no evidence that adding special seed or concoctions helps the performance of a septic tank. However, some of the grease-decomposing cultures have been shown to be effective in other locations in sewer systems and may be effective in reducing a problem with grease buildup in septic tank scum. The use of additives is not a substitute for the recommended periodic inspections.

Figure D.2 shows a typical two-compartment tank in both plan and elevation. Most tanks have a single compartment. The single- and two-compartment tanks are alike except for the intermediate baffle wall.

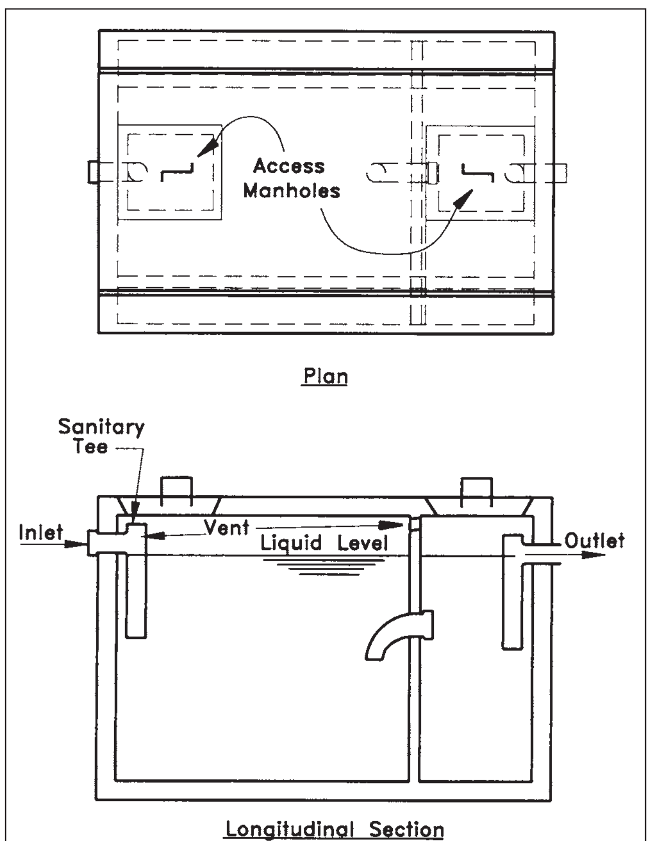

Figure D.2 Typical two-compartment septic tanks. (U.S. EPA, 2002)

Disposal Methods. The septic tank, if properly designed and maintained, removes the settleable and floatable material from the wastewater flow. Much of the material initially removed by settling from the flow and the nonsettleable organics are carried from the tank in the effluent as either dissolved or finely divided solids. The tank effluent is septic and is high in solids and reduced chemical forms such as ammonia and sulfides. The biochemical oxygen demand of the effluent will vary greatly in strength diurnally, weekly, and seasonally. An average value of the biochemical oxygen demand from a properly operating septic tank is approximately 150 mg/L. The flow from a septic tank always requires further treatment as a part of the disposal process.

Suitable technology is available for safely treating and disposing of septic tank effluent on land, beneath the land surface, into surface waters, and into the atmosphere. The most common methods of treatment and disposal for septic tank effluents, such as from single-family homes, small clusters of homes, or flows from industrial of commercial establishments, are subsurface soil absorption systems, evaporation systems, biofilters, and aerobic treatment with or without filtration. Effluents from filtration and aerobic systems are discharged to surface waters. The selection of the most suitable method for a particular application is usually straightforward.

Subsurface soil absorption systems are the most widely used and represent the most economical and reliable method if soil conditions are suitable. The individual homeowner is not prepared to maintain a system that requires daily or even monthly attention. The soil absorption system, if properly designed and protected from major hazards such as tree roots and heavy surface loads such as vehicle traffic, should operate for many years with little maintenance required. Any wastewater treatment system that requires special maintenance and land use detracts from the value of the land as a building site and makes the completed dwelling less marketable. The following sections present design information for the most common types of on-site treatment and disposal methods.

Subsurface Soil Absorption. As noted, where soil conditions are suitable, subsurface soil absorption is the desired method of septic tank effluent treatment and disposal. This method is simple and reliable, requires little attention, and has the least cost of installation. This method involves distributing the flow through a subsurface system, where it is absorbed and treated as it percolates through the soil. It is important that the flow be applied at an intermittent dosing rate such that the soil drains to an unsaturated condition between applications. The normal rate of water use in the home, such as the flushing of a lavatory or shower, and with little water draining to the septic tank between such uses in the home, automatically gives the intermittent dosing. Larger systems may incorporate pumps or dosing devices to ensure intermittent application. System efficiency is improved by incorporation of a holding tank and pump into the system to provide for filling the absorption field distribution piping with each pump cycle. This may mean that the absorption field is dosed less than once per 24-hour period. However, special dosing facilities are not normally provided except where they are needed because of poor soil conditions.

Figure D.3 shows a section of a typical absorption trench. Care should be exercised during the digging of the trench to ensure that the bottom is maintained on a constant grade with no depressions, as this causes septic tank effluent to accumulate at the low points. It is important that the flow be distributed as evenly as possible along the entire length of the trench. The trench bottom should be sloped about 3 inches per 100 feet. The bottom and sides of the trench should be scarified with a rake or similar tool to break the smooth, compacted surface formed by the excavating bucket. The trench is then filled with about 6 inches of clean, durable gravel. A 4-inch perforated plastic pipe is placed on the gravel surface after the gravel has been raked to the same uniform slope as the trench. This slope (0.25 percent) of the pipe should provide good distribution of incoming flow but not be so steep that all the flow runs to the low end before leaving the pipe. The pipe is then covered with additional clean gravel. A plastic sheet is placed on top of the gravel to prevent soil from infiltrating into the gravel voids, and the remainder of the trench is then backfilled with native soil. The trenches are normally less than 5 feet deep but should be deep enough to provide at least 1 foot of soil cover over the gravel.

When septic tank effluent is distributed to the soil absorption trench, a biological film develops in the rock fill and on the trench wall. The biological film on the soil trench interface becomes semiclogging. It is important that the surface area of the gravel be sufficient such that this film does not become so massive as to block percolation into the soil. If the percolation through this film or mat becomes less than the application rate to the trench, the system will fail. Some state and local authorities may require that two absorption fields be provided and that a distribution box be installed to permit seasonal or annual rotation between the two fields. This technique provides a rest period for the system, allowing the growth on the stone and the soil interface to decompose, returning the trench to essentially a new condition.

Soil acts as a filter, exchanger, or absorber, and provides a surface area for biological growth. The interface mat and retention time in the soil provides for entrapment and die-off of pathogens. Ammonia nitrogen and phosphorus are adsorbed onto the soil particles. Organic matter is adsorbed and decomposed by the biological growth in the trench, which together with the filtering action of the mat and the soil between the trench and the ground water table, produces a treated effluent that does not pollute the ground water. A minimum of 2 feet, and preferably 4 feet, of soil should exist between the trench bottom and the water table. It is important that the soil strata between the trench bottom and the water table not be saturated, as this reduces adsorption and causes channeling, resulting in poor treatment. Very porous

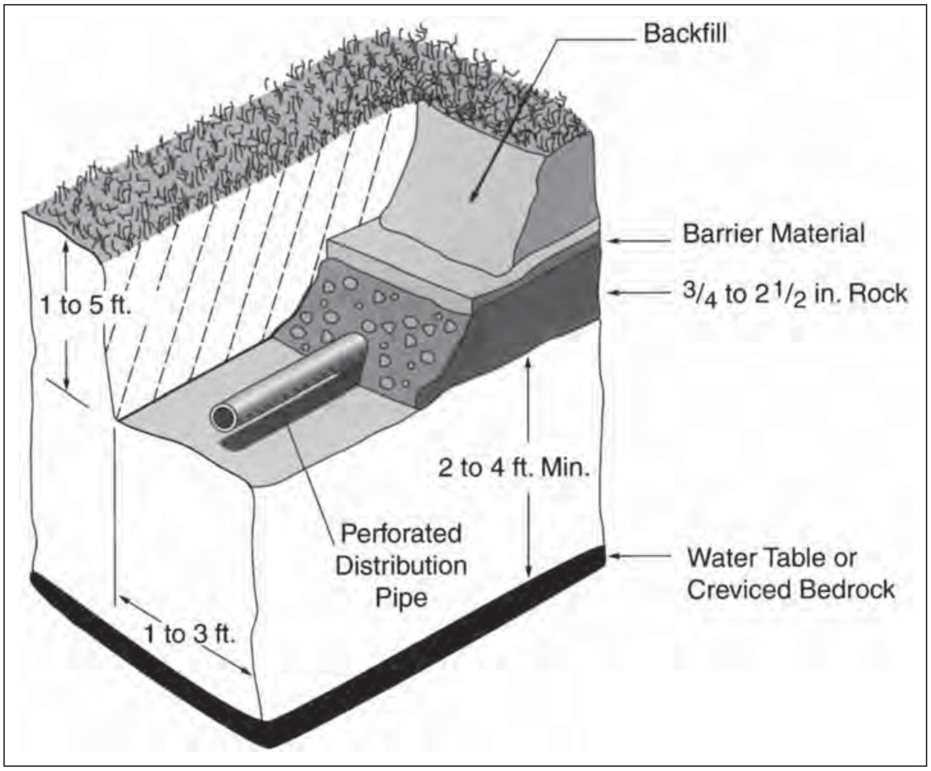

FIGURE D.3 Typical soil absorption trench. (U.S. EPA, 2002)

soil such as coarse sand does not give proper treatment, as the flow moves rapidly to the water table without receiving proper treatment.

Soil is composed primarily of mineral matter, resulting from the weathering or decomposition of rock. Residual soils are those found directly above the bedrock source. Many soil deposits have been transported from distant locations, primarily by water (alluvial deposits). Soil may contain refractory or relatively stable organic matter called *humus,* which changes the physical and chemical characteristics of the soil. Soil containing this mixture of refractory and stable organic matter is called *topsoil.* It is normal to find a wide variation in soil types at any location. Most open cuts show more than one soil type. The soil profile in a highway cut, for example, may show several soil types or layers.

The type and condition of the soil, percolation rate, and depth to bedrock or water table are important parameters in the location and design of an absorption field. If the soil percolation rate is inadequate, the trench will become saturated and the system will fail. If the flow does not percolate through a sufficient depth of unsaturated soil, adequate treatment will not be provided, resulting in ground water pollution.

Significant information is available on soils for most locations. The U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS, formerly the SCS) Soil Survey Maps are thought to be available for all areas of the country. These maps are usually compiled and issued for a local governmental jurisdiction such as a county. They are also available from the local NRCS office. Furthermore, the Agriculture Extension Service maintains local and state offices and is a local source of soil information. Soil survey maps include aerial photographs, soil classification, interpretative data on potential uses, and a description of each soil series. These maps are compiled at small scale and, while very useful, a site-specific soil survey is likely needed to complete an evaluation of a site.

An experienced individual is required to conduct a field soil survey and prepare a report. The first step in conducting a site-specific soil survey is an investigation into the operation of other absorption fields in the area. This information is normally available from the local agency having permitting responsibility for septic tank systems. This agency can also provide information on soils in the area and their general suitability for soil absorption fields. The next step is the collection of field soil types and conditions. Field soil data can best be obtained by using a backhoe to dig a short length of trench to sufficient depth to expose the soil profile 4 to 6 feet below the proposed elevation of the absorption trench. The exposed soil profile allows the investigator to determine the soil texture (the relative fractions of the various sizes of soil particles), soil structure (the aggregation of soil particles into clusters), soil color (a good indication of drainage characteristics—standard color charts are available), soil mottling (also described by the color, streaks, or areas of darker color), soil profile, and the presence of seasonally saturated soils. Seasonal saturation can be identified during the wet season or generally by the color or mottling of the soil. Addi-

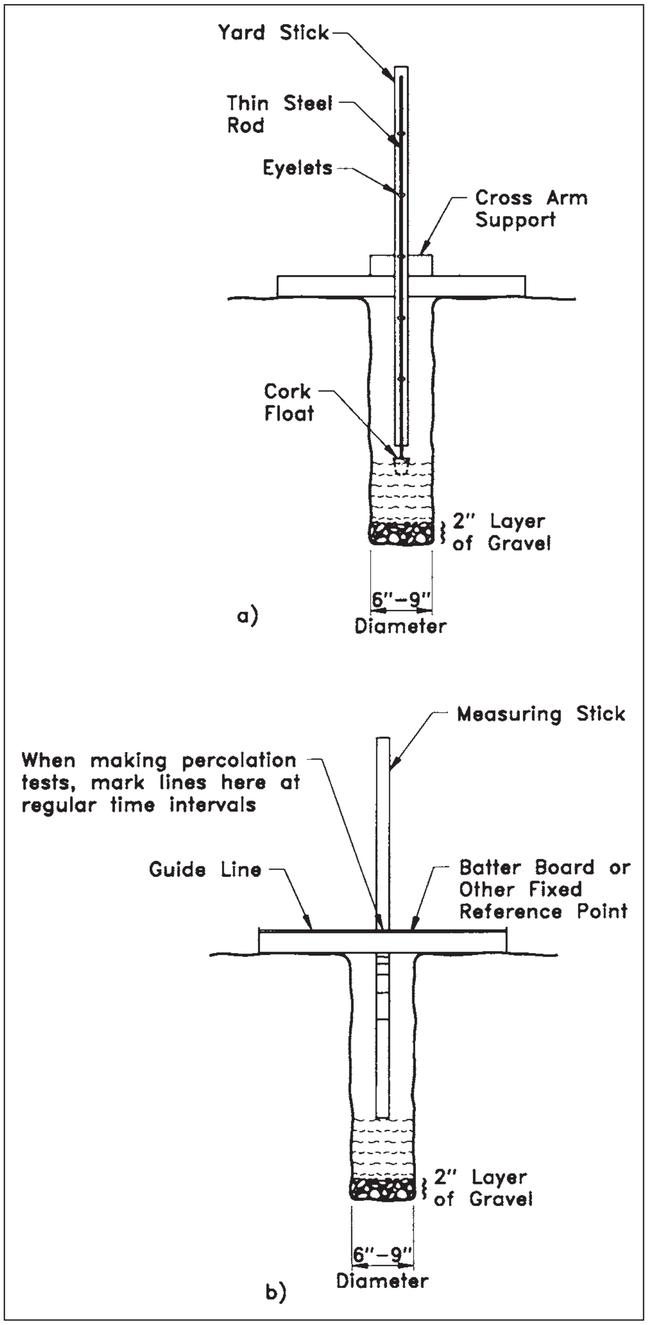

FIGURE D.4 Typical percolation test setup. (U.S. EPA, 2002)

tional information on mottling can be found in Chapter 15 of this text.

If the soil survey shows an area suitable for a soil absorption treatment and disposal system, a percolation test is conducted. While a percolation test is subject to wide variability and often-poor reproducibility, it remains the principal means of determining the hydraulic conductivity for an area and thus the basis of the absorption field design.

A percolation test is conducted by boring three or more test holes, 6 inches in diameter, to the depth of the proposed absorption trench. The borings are located so as to cover the entire area of the proposed absorption field. If the soil profile varies significantly in the test holes, additional holes may be needed. Figure D.4 shows a typical percolation test setup. After the hole is bored, the sides are scarified to eliminate the smeared compacted surface left by the auger. Two inches of gravel are placed in the bottom of the hole to prevent scour, and the hole is then filled with 27 inches of clean water. This water depth is then maintained for at least four hours to soak the soil around the hole. The water level is then adjusted to a 6-inch depth over the gravel and the rate of fall in the surface is observed at a suitable interval, usually 30 minutes but it will depend on the percolation rate of the soil. Water is added, as needed, to maintain the 6-inch depth, and measurements of the surface fall rate are recorded until the rate of fall becomes constant for at least three successive observations. The percolation rate is described as the time in minutes required for the water surface to fall 1 inch.

The length of the required absorption trench is established by the percolation rate, with the application rate being based on the area of trench bottom. Table D.2 gives some recommended application rates for the indicated ranges of percolation rate. The maximum length of a trench is usually 100 feet because of the inability to distribute the flow over greater lengths. A minimum of two trenches and 200 feet of trench length should be provided for a system. For example, a four-bedroom house is assumed for design purposes to produce 150 gpd/bedroom, or a total flow of 600 gpd. If the percolation rate is 45, the application rate to be used in the design of the absorption field is found from Table D.2 to be 0.45 gpd/ft^2. Thus, the absorption trench area would be 600 gpd/0.45 gpd/ft^2 = 1333 ft^2. This is equal to 667 linear feet of a 2-foot-wide trench. Eight absorption trenches, each 2 feet wide and 83 feet long, are selected for the design.

TABLE D.2 Rates of Septic Tank Effluent Application

Soil Texture	Observed Percolation Rate	Application Rate*
Gravel, coarse sand	>1	not suitable
Coarse to medium sand	1–5	1.2 gpd/ft^2
Fine sand, loamy sand	6–15	0.8
Sandy loam, loam	16–30	0.6
Loam, porous silt loam	31–60	0.45
Silty clay loam, clay loam	61–120	0.2

*As with all criteria for on-site systems, local requirements may be different. The engineer must always be guided by the regulations of the local permitting agency. Special requirements may apply to areas having a percolation rate greater than 60 minutes per inch.
(U.S. EPA, 1979.)

Trenches are usually spaced 6 or more feet apart, center to center.

Regulations also limit placement of septic tank soil absorption fields with respect to buildings, wells, and other activities. Safe distances vary from site to site, but generally they should not be located within 50 feet of wells and surface waters or within 10 feet of building foundations and property boundaries. Absorption fields are located in well-drained areas, with crest of slopes or convex slopes being desirable. Concave slopes are undesirable because they are usually drainage ways and subject to surface water percolation.

Areas having percolation rates less than 1 minute per inch can be used by replacing 4 feet of soil below the trench with suitable soil, if permitted by local codes. A 4-foot depth of proper soil below the trench ensures protection of the ground water below. The flow path for a septic tank soil absorption field may have the components shown in Figure D.5. It is not uncommon for a pumping station (as shown) to be required as part of the system. Normal open impeller centrifugal pumps can be used with septic tank effluent, but a grinder pump is required if pumping is needed prior to the septic tank. Small grinder pumping stations are available for this purpose.

When pumping is not required, the septic tank effluent flows directly to the distribution box. The distribution box is designed to distribute the flow equally to all the absorption lines. Systems sometimes have a distribution box to divide the flow equally to two or more additional boxes, which in turn supply the absorption lines. Figure D.5 shows a field selection valve that is used to direct flow to the proper field. Where field alternation is required, the valve is included as a means of directing the flow to the proper field. When used, the fields are usually alternated annually, but some agencies may require alternation that is more frequent. A single distribution box can be used to alternate specific trenches. For example, the eight trenches served by a single box in Figure D.5 could be divided at the box into two four-trench systems by properly placing a slide gate in the box to permit the homeowner to direct the flow as required. Each of the four trench systems would be designed to handle the total flow.

Watertight pipe is installed from the distribution box to the beginning of the absorption trench. The absorption trenches may be curved to follow the surface contour of the land. The absorption trenches served by a single distribution box are all the same length so that flow application is uniform. The designer has unlimited options in laying out the absorption field to accommodate soil conditions and topography.

Mound Systems. The mound system is an engineered modification of the conventional absorption field to overcome problems with slowly permeable soils and insufficient depths of unsaturated soil. Although the technology behind mound systems has been known for several decades, the practice, while not widespread, is now finding uses with a variety of soil conditions. A mound system is an absorption system that has been constructed above the natural soil elevation. A mound system is constructed above or partially above grade by importing fill that has suitable characteristics. Note that an absorption bed, rather than trenches, is employed in the mound system. No other general layout changes are required in a mound soil absorption field system.

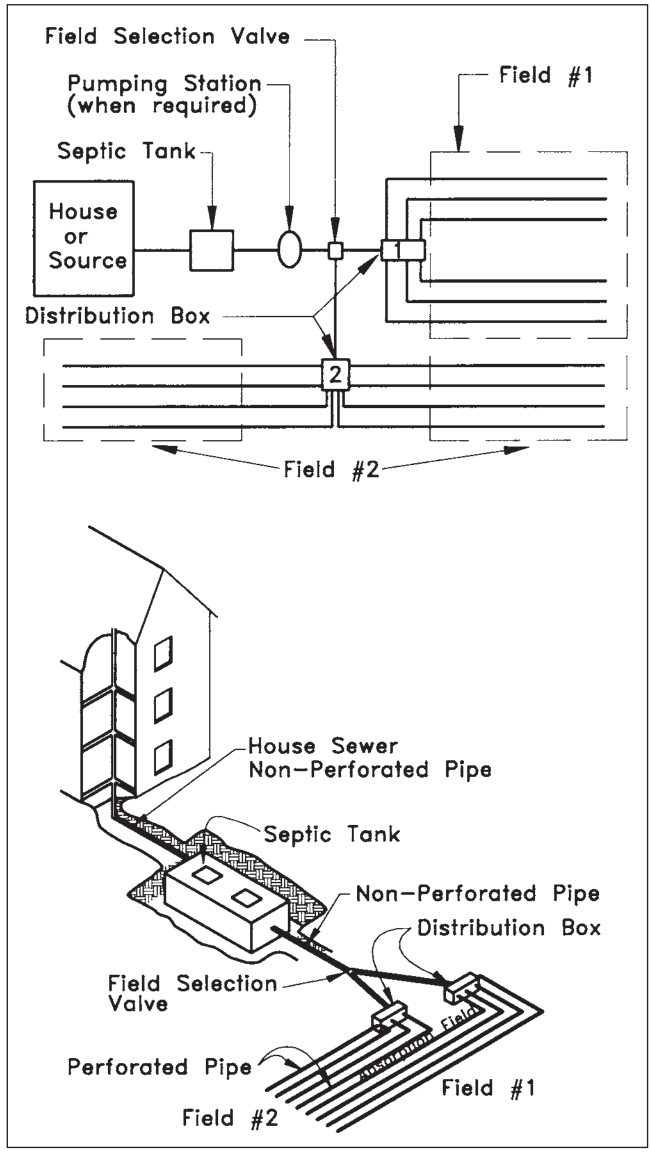

Figure D.5 Typical dual-field septic tank soil absorption field layout. (U.S. EPA, 2002)

A mound system can be designed to overcome some site conditions that would normally make a site unsuitable for an absorption field. These conditions include soils having a high percolation rate, shallow depths of suitably permeable soil over creviced or porous bedrock, and permeable soils with a shallow depth to the water table. When the bottom of the absorption trench is sited over 4 feet of suitable soil material, proper treatment of the wastewater will be provided. The soil below this level will be less prone to clog because only well-treated water will pass from the imported soil, making areas with soils having low permeabilities more suitable. In addition, the mound system provides proper treatment for areas having a shallow depth to the water table or to porous bedrock, eliminating the potential for ground water pollution.

Four views related to a typical mound system are shown in Figure D.6. Note that the absorption bed is constructed similar to a conventional bed except for being in an artificial fill.

Design criteria for a mound system are as follows:

- Land topography—locate in well-drained areas.
- Separation from wells, etc.—same as for a conventional absorption field.
- Natural soil profile—prefer relatively undisturbed area, avoiding filled areas until a thorough study has shown that filled changes will not affect water movement.
- Unsaturated soil depth—a minimum of 2 feet of natural unsaturated soil should exist over porous or creviced rock or a high water table.
- Depth to impermeable soils or rock barrier—3 to 5 feet. A sufficient depth of permeable soil must exist over impermeable strata to carry the percolating water away from the mound to prevent the treated effluent from seeping to the surrounding natural ground surface. The required depth depends on soil permeability, climate, and topographic site conditions. Frost penetration depth must be considered. Each site must be evaluated.
- Percolation rate—natural soil should have a percolation rate of not more than 120 minutes per inch. The rate is measured at a depth of 20 inches, or 4 inches above the water table depth. Where shallow soils exist over pervious or creviced bedrock, the percolation test is run at a 12-inch depth.

Mound dimensions as designated in Figure D.6 are as follows:

Fill depth D and E	1 foot or more
Absorption bed depth F	0.75 feet or more
Cap at edge of bed G	1 foot
Cap at center of bed H	1.5 feet

Since mound systems are installed in a raised area, the percolation field is dosed by a pump following the septic tank. The use of a pump wet well capacity equal to 25 percent of the design daily flow provides four bed dosings per day. The pressure loading ensures the flow is spread to the entire bed with each dosing.

Table D.3 provides data as required for sizing the absorption bed. The bed area depends on the permeability of the fill material. The selection of fill material may depend on transportation costs. The most suitable material may not be found locally, in which case a material requiring a greater area may be used.

Basal area requirements—(B times A) + I in Figure D.6—is the area to be provided to ensure seepage into the natural ground before reaching the bottom of the mound area. Dimensions J and K are based on a three-to-one side slope, as shown in Figure D.6. B and A are the absorption bed dimensions. Dimension I is the downslope distance required to provide the basal area. Basal area requirements are determined by the infiltration rates given in Table D.4.

EXAMPLE

Determine the absorption bed area and mound basal area to serve a three-bedroom house. Medium sand is to be used for fill material and the natural soil is a silty clay loam having a percolation rate of 50 min/inch.

Absorption bed area requirements from Table D.3, infiltration rate = 1.2 gpd/ft^2.

Flow = 450 gpd, bed area = 450 gpd/1.2 gpd per ft^2 = 375 ft^2.

From available area for mound, a bed length of 50 ft is selected; therefore, bed width is 7.5 ft.

Basal area requirement determined from infiltration rate found in Table D.4.

Infiltration rate = 0.5 gpd/ft^2. Bed length dimension B is 50 ft.

Basal area = 450 gpd/0.5 gpd per ft^2 = 900 ft^2. Therefore, dimensions I + A = 18 ft. Dimensions L and W are then determined from the topography and depth of the mound.

Evapotranspiration (ET) and Evapotranspiration/Absorption (ETA) Beds. ET and ETA beds are used as means of liquid disposal through evaporation and transpiration at some locations where subsurface absorption or discharge to a surface discharge is not feasible. ETA beds may also be designed to augment subsurface absorption at locations where the percolation rate is too low for absorption to be effective alone. The system functions best with a high-quality influent, such as produced by an aerobic process or by an intermittent slow sand filter. However, these systems can be designed to function where the influent is from a septic tank.

ET beds function by designing a system where capillary action brings the treated liquid to the surface, where it is removed by evaporation and/or transpiration. Planting trees and bushes having a large silhouette can improve the appearance of the bed area and aid in water removal. Transpiration is moisture uptake by the vegetative roots followed by the passage of watery vapor to the atmosphere through the surface of leaves or other plant membranes or pores. However, transpiration is effective only during the growing season, and a vegetative cover reduces evaporation throughout the year.

If evaporation is to be effective, three conditions must be present. First, there must be a continuous supply of heat to

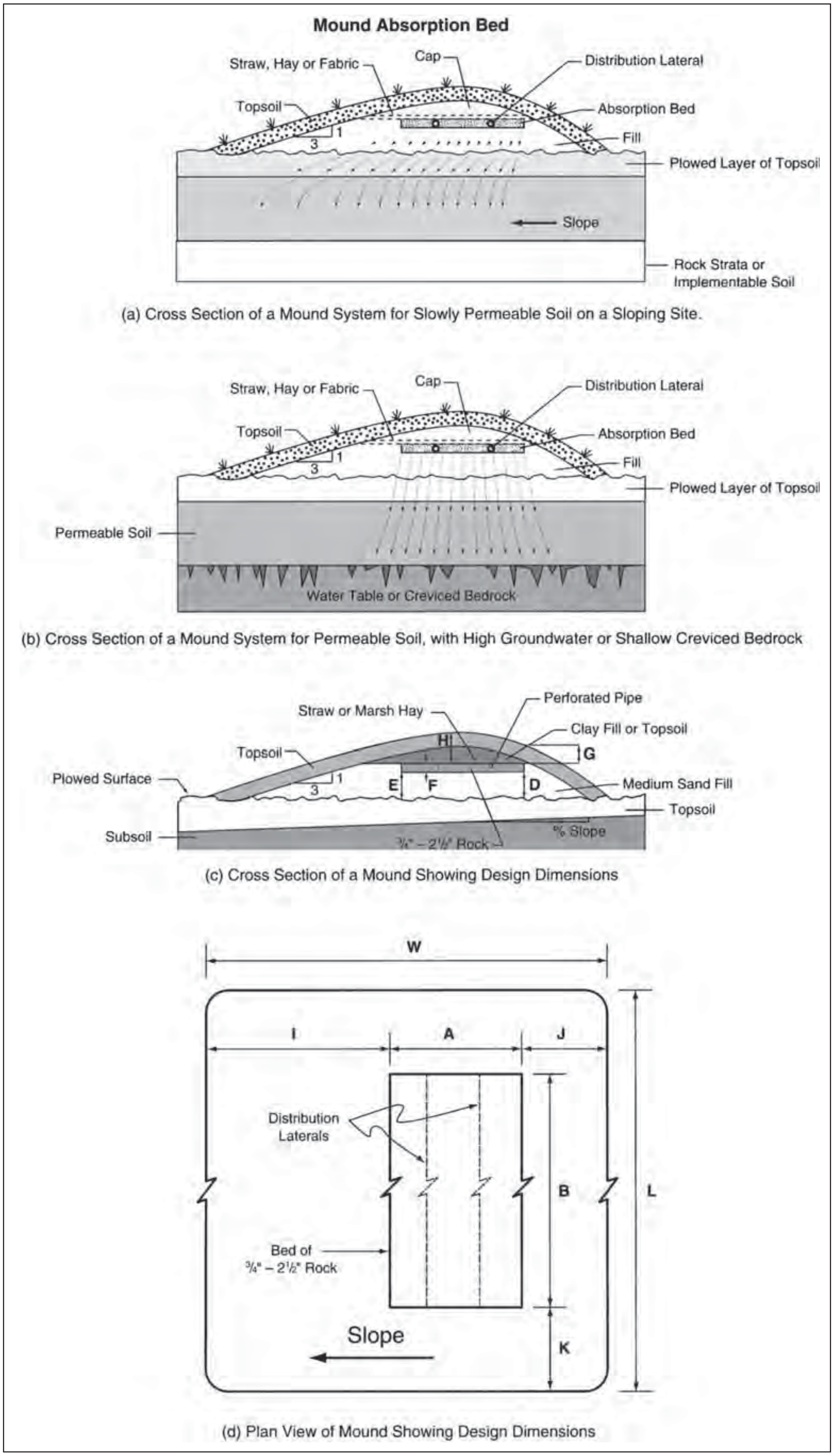

Figure D.6 Mound absorption bed. (U.S. EPA, 2002)

TABLE D.3 Absorption Bed Area Requirements

Fill Material	Characteristics*		Design Infiltration Rate
Medium sand	25%	0.25–2.0 mm	0.2 gpd/ft^2
	<30–35%	0.05–0.25 mm	
	<5–10%	0.002–0.05 mm	
Sandy loam	5–15%	clay content	0.6
Sand/sandy loam mix	88–93%	sand	0.2
	7–12%	finer-grained material	
Bottom ash			1.2

*Percent by weight.
(U.S. EPA, 1979.)

meet the latent heat requirement for evaporation (approximately 540 calories per gram (cal/g) of water evaporated at 15°C). Second, a vapor pressure gradient must exist between the evaporative surface and the atmosphere to remove vapor by diffusion and convection. Meteorological factors, such as air temperature, humidity, wind velocity, and radiation, influence both energy supply and vapor removal. Both evaporation and transpiration may be reduced to near zero in the winter months. Winter rainfall generally makes ET negative during this period. Third, the moisture must be brought to the soil surface. The soil material must be fine textured for capillary transport to be effective, but not so fine that water movement is restricted. These three requirements for effective evaporation limit its applicability to a majority of sites. The dissolved salts from the water supply are deposited at the surface as evaporation occurs and may influence the long-term operation of the ET bed. Excessive growth within the bed, resulting from the organic loading contained in the wastewater, may further restrict water movement.

All rainfall seeps into the bed, which adds to the evaporative requirements for the process. ET bed design must provide for the maximum annual rainfall expected at least every 10 years. A moisture balance (water budget) should be carried through several years of a projected wet rainfall cycle.

A typical ET bed is shown in Figure D.7. The bed consists of 1.5 to 3 feet of select sand over an impermeable plastic liner. Uniform sand having an average size of 0.10 millimeters has been found to be capable of raising water about 3 feet through capillary action. A perforated plastic piping system with a rock cover is provided to distribute the influent throughout the bed. The area is graded to direct all runoff away from the bed.

An ET bed can function only in areas having a low annual rainfall. Annual evaporation should exceed the rainfall by at least 24 inches. The average annual temperature must be sufficient to supply the latent heat required for vaporization. These restrictions limit acceptable operation of ET systems to the southwestern section of the United States. Much of the Upper West region between the Mississippi basin and the east side of the Cascade Range has a high positive evaporation rate, but low winter temperatures make the operation less efficient. Most likely, areas that permit the installation of ET systems will have developed local design criteria.

Biofilters. The use of biofilters is becoming increasingly common in on-site wastewater treatment. Biofilters containing foam, plastic, or other types of media that will support biological growth and produce a higher-quality effluent than a septic tank drainfield.

In most applications, the effluent from a septic tank is pumped to a distribution system located above the biofilter and allowed to trickle through the media supporting the biological growth. Because the media used in biofilter applications is selected for their high surface area–to–volume ratios, they can tolerate relatively high loading rates. The effluent quality after treatment through a biofilter is much better than from a septic tank. Therefore, it can in some locations, with disinfection, be discharged to a receiving stream. The engineer should review the regulations of the permitting authority before selecting this method of disposal, as not all states permit the direct discharge of biofilter effluent to surface waters.

More typically, the effluent from a biofilter is discharged below the surface of the ground in small trenches similar to a conventional absorption field. The better-quality effluent produced by the biofilter, however, can significantly reduce the size of the drainfield that is required. This can prove advantageous in developments where the size of the lots is smaller than typically required for conventional absorption fields or where the type or depth of the soils is not ideal for conventional absorption field applications. With the right soil conditions, biofilters can also be placed on a subsurface gravel pad with the effluent allowed to soak into the soil below and around the unit. See Figure D.8.

TABLE D.4 Infiltration Rates for Determining Mound Basal Area

Natural Soil Texture	Percolation Rate	Infiltration Rate
Sand, sandy loam	0–30 min/in.	1.2 gpd/ft^2
Loams, silt loams	31–45	0.75
Silt loams, silty clay loams	46–60	0.5
Clay loams, clay	61–120	0.25

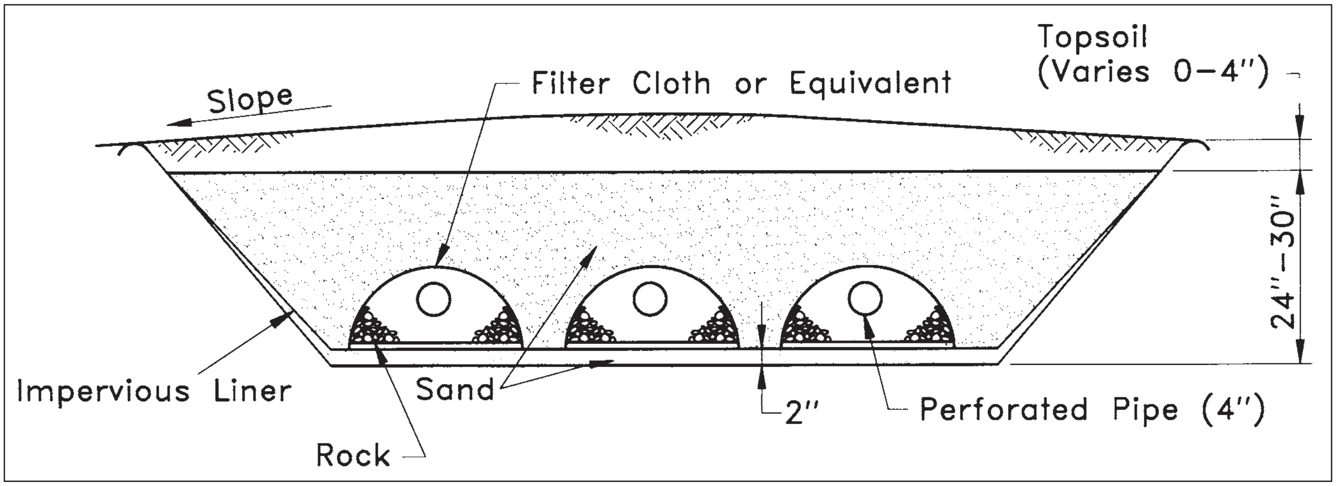

Figure D.7 Cross section of a typical ET bed. (U.S. EPA, 2002)

A biofilter can be designed as a single-pass or as a recirculating unit. In single-pass units, the liquid passes through the filter once, as the name implies, before being discharged. In recirculating units, the liquid is collected at the bottom of the biofilter and returned ahead of the filter, where it mixes with the septic tank effluent and is sent through the biofilter again. Recirculating biofilters typically dose effluent between 6 and 12 times before discharge.

As with all filtration systems, biofilters should be designed with a backwash device capable of forcing clean water upward through the unit with enough velocity to scour and clean the media. Single-pass filters are often designed without backwash capabilities. In those instances, the treatment capability of the biofilter is maintained by periodically replacing the filter media.

Aerobic Treatment Systems

As noted earlier, the use of on-site systems employing absorption fields is appropriate for approximately one-third of the land in the United States. In those areas where the soil conditions are not conducive to the use of absorption fields or in those areas where there isn't sufficient space for the installation of a traditional septic tank/absorption field system, homeowners have increasingly turned to aerobic treatment systems to meet their treatment needs.

Residential aerobic treatment systems employ a one-piece unit that is divided into multiple chambers. These chambers typically include a pretreatment tank, where the influent enters the unit. The inlet and outlet are designed to still the incoming flow velocity and trap the scum layer.

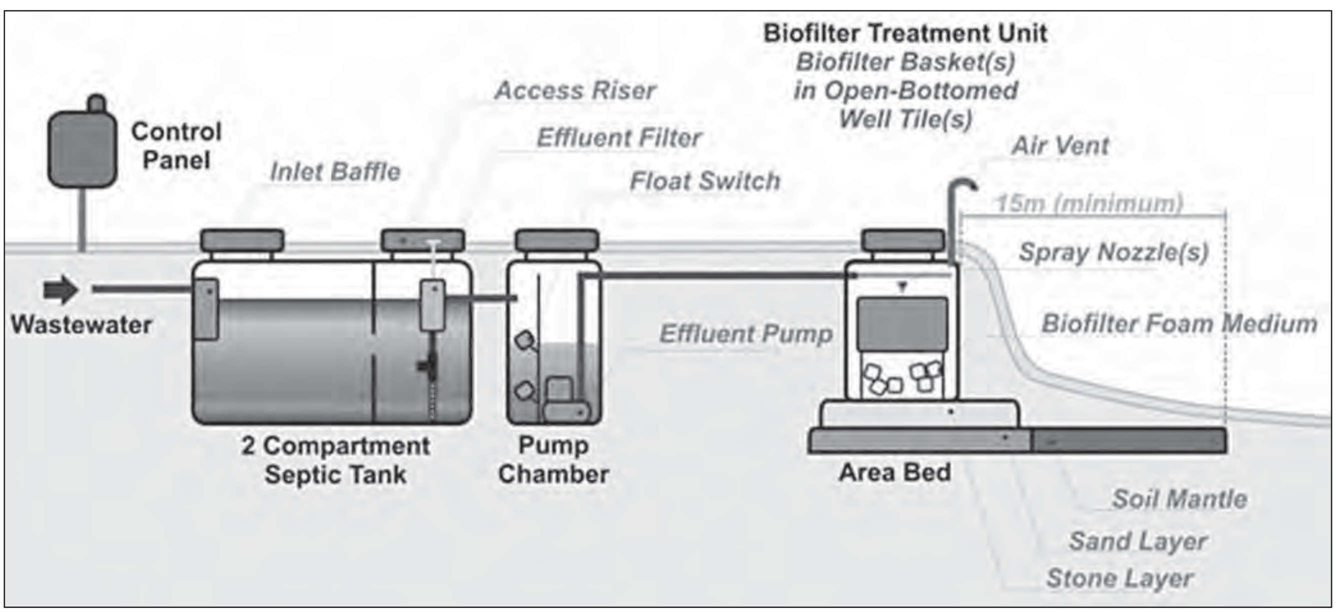

Figure D.8 Section view of a biofilter. (U.S. EPA, 2002)

A full-depth baffle wall separates the pretreatment tank from the aeration chamber, where oxygen is pumped into the wastewater.

The forward flow from the aeration chamber enters a clarifier chamber, where the clear, odorless effluent rises to the surface. An outlet pipe located at the top of the chamber allows the effluent to exit the clarifier and pass through a chlorination unit before it is discharged to a holding basin. The disinfected effluent is stored in the holding basin until it is pumped from the basin and used to irrigate the lawn and landscaping on the property. See Figure D.9.

Methods of irrigation are generally prescribed by the state regulatory agency having jurisdiction over the development of the property; however, the two most common methods are drip irrigation and surface irrigation, although the use of the latter method is generally restricted to the more arid parts of the United States.

All on-site aerobic systems should have a high-water alarm to notify the owner and/or operator of a malfunction, and sludge needs to be wasted from the system about every six months or removed as required.

Normally the sludge is removed by a firm that pumps septic tanks and can take the sludge to a septage disposal facility. All surface discharges should be disinfected. The simplest means of accomplishing disinfection for small flows is by use of a tablet chlorinator, as shown in Figure D.10. Calcium hypochlorite tablets are stacked in the feed tube, and the filter effluent flows through the chamber. The size of the chamber and number of feed tubes are varied in the construction to provide the proper chlorine dosage. The flow is not retained in the chlorinator but in a holding tank called a contact tank, where a 30-minute contact time is provided to ensure the kill-off of pathogens. After the 30-minute contact period, 1 to 3 mg/L of chlorine residual should remain.

Some locations may require dechlorination after the 30-minute contact time and before discharge. A tablet sulfonator, having a design similar to the tablet chlorinator, is available for this purpose. The sulfonator can be placed on the discharge line from the contact tank to oxidize the residual-free chlorine forms. The reaction is instantaneous, and only flow through the chamber is required (no contact time needed, as required for disinfection).

The homeowner or developer should use the services of a qualified engineer in selecting an on-site treatment unit. It is recommended that the local health department be contacted for information on the types of units that are being marketed in the area and the reliability of operation of existing units. Useful information on types of units available can be obtained from several sources. The National Sanitation Foundation (NSF) provides testing services to equipment manufacturers of small treatment units. Some regulatory agencies require that the NSF test new equipment before approving its use.

On-site wastewater treatment is a developing field. Cur-

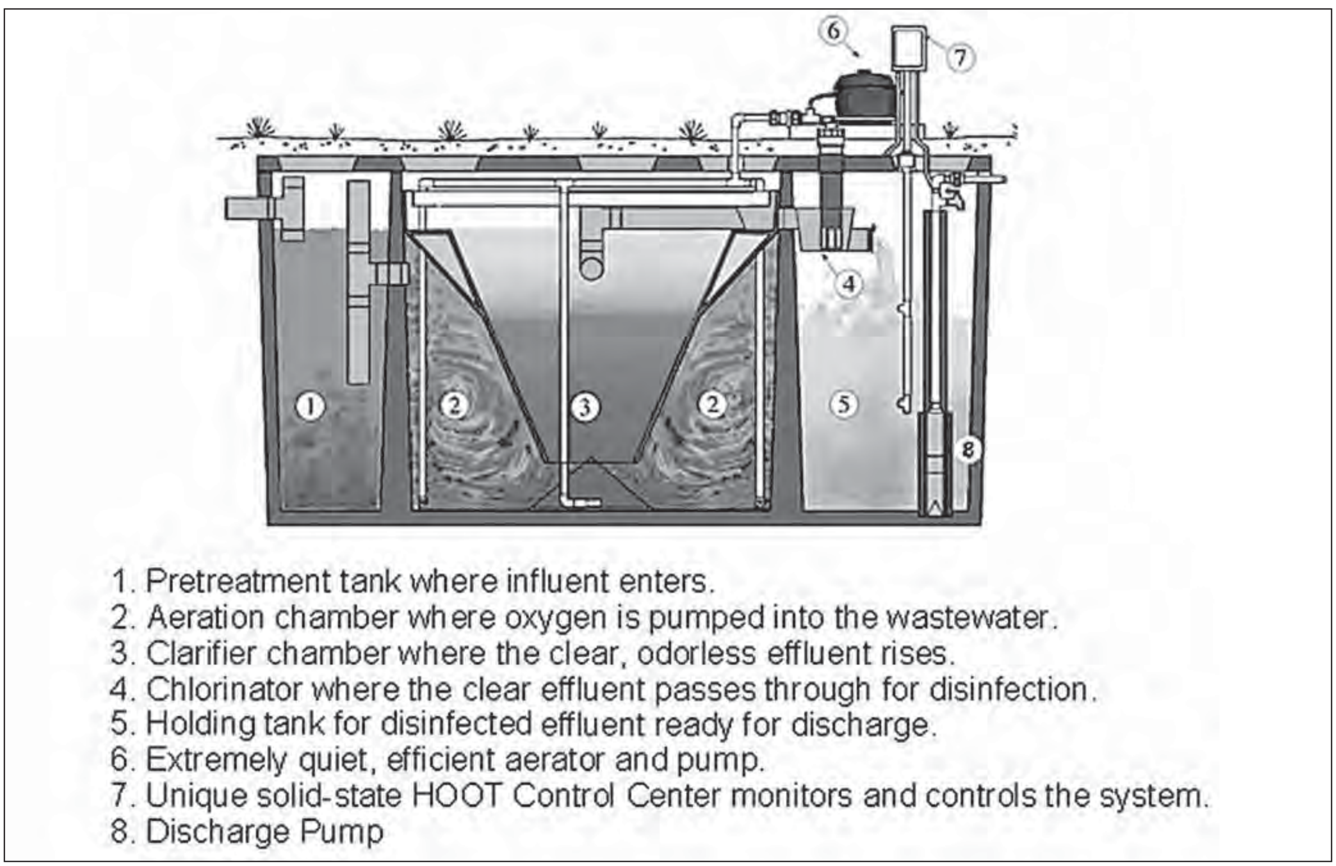

Figure D.9 Section view of a residential aerobic treatment system. (U.S. EPA, 2002)

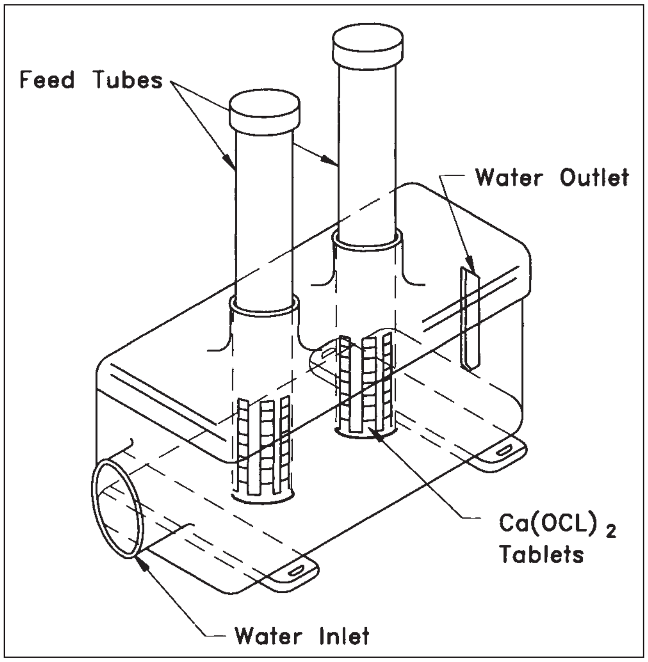

FIGURE D.10 Tablet chlorinator. (U.S. EPA, 2002)

rent information on available technology is available from the sources listed in Table D.5.

ON-SITE SYSTEMS FOLLOWED BY A SURFACE DISCHARGE

General Information

Relatively few homes are sited to permit a surface discharge of treated wastewater. Surface discharges include discharge to a permanent flowing stream, an intermittent stream, a dry ditch, or a pond or lake. For single-family homes, this means a building lot size of more than 1 acre is needed to accommodate treatment facilities. Also, the cost of installation, operation, and maintenance is greater than for the on-site absorption system. However, several suitable treatment technologies are available for serving single-family homes as well as entire residential subdivisions. Because of the cost associated with the required treatment units, their use is generally limited to locations where land and home values are substantial and other alternatives are not available for wastewater management.

A permit is required by federal law for all surface discharges. National Pollution Discharge Elimination System (NPDES) permits were established under the 1972 Water Pollution Control Act (P.L. 92-500), commonly known as the Clean Water Act. Most of the states now administer this program and issue a state permit. The level of treatment required depends on the discharge conditions, but in all instances secondary treatment or the equivalent followed by

TABLE D.5 Sources for Information on On-Site Wastewater Treatment

EPA National Small Flow Clearinghouse P.O. Box 6064 Morgantown, WV 26506-6064 Toll-free 1-800-624-8301 www.nesc.wvu.edu	Your State Water Quality Agency Your State USDA Farmers Home Administration Office
National Sanitation Foundation P.O. Box 130140 789 W. Dixboro Road Ann Arbor, MI 48113-0140 Toll-free 1-800-NSF-MARK www.nsf.org	EPA Center for Environmental Research Information 26 W. Saint Clair Cincinnati, OH 24268 www.http://es.epa.gov/ncer/
National Rural Water Association Wastewater Technical Program (Local office in most states) www.nrwa.org	Catalog data from purveyors of wastewater treatment equipment
National Association of Towns and Townships 1522 K Street N.W., Suite 730 Washington, DC 20005 (202) 737-5200 www.natat.org	EPA Regional Office

disinfection is required. Secondary treatment involves subjecting the wastewater flow to biological treatment and clarification. Effluents from intermittent sand filters are superior to those from conventional secondary biological processes. Both *biochemical oxygen demand* (BOD) and suspended solids must be reduced to less than 30 mg/L. Discharges to small streams where little or no dilution is provided, to impounded water like lakes and ponds, and to special designated waters such as shellfish harvesting areas or trout waters may be prohibited or require treatment that is more stringent. Treatment beyond the secondary level may involve nitrogen and phosphorus removal and/or a greater reduction in BOD and suspended solids.

Intermittent Sand Filtration

This technology has been used for many years with excellent success. There are many sand filters in use throughout the United States, treating wastewater from individual homes, small commercial and institutional developments, and small clusters of homes. If properly designed and operated, an intermittent sand filter produces an effluent having very low BOD and suspended solids. The process is appropriate as an on-site method of treating septic tank effluent prior to a surface discharge.

An intermittent sand filter is a bed of sand 24 to 36 inches deep and underlain with graded gravel and a flow-collecting manifold. General design criteria are given in Table D.6. Conditions that have significant impact on the performance of an intermittent sand filter include:

- *The quality of the applied wastewater.* A septic tank effluent should be considered the minimum acceptable pretreatment. Furthermore, grease and solids loading should be kept to a minimum.
- *Temperature and dissolved oxygen.* The organics removed by the filter must be decomposed by biological activity. The rate of decomposition is temperature dependent, which limits the loading rate to the filter.
- *Sand size and uniformity.* The allowable loading rate for a sand filter is affected by the sand grain size, filtration rate, penetration depth of particulate matter, and effluent quality. The uniformity of the sand establishes the porosity, with a small uniform grain size giving the best filtration and highest porosity. The effective size is the size where 10 percent by weight of the particles are smaller = E10. Uniformity in size is expressed by the *uniformity coefficient,* which is the sieve size that will pass 60 percent of the mass (E60) to the effective size = E60/E10. A uniformity coefficient of less than 4 is considered acceptable, but a material having a lower value gives better performance. The small additional cost of a uniform sand materially improves the long-term operation of the filter, should reduce the maintenance cost, and improves the effluent quality. It is important that the sand size be uniform throughout the filter.

The filters remove pollutants by trapping them on the sand surface, by straining the flow as it percolates through the bed, and by absorption and adsorption by the biological growth within the filter. Excessive loading results in filter clogging, which causes ponding on the filter surface, leading to deterioration of effluent quality and, hence, filter failure. Good treatment depends on oxygen being drawn into the bed to

TABLE D.6 Design Criteria for Intermittent Sand Filters

ITEM	CRITERIA
Pretreatment	Minimum—septic tank or equivalent
Hydraulic loading, gpd/ft^2	1–5 gpd/ft^2, smaller buried filters, 1 larger open filter to 5 gpd/ft^2
Filtering media	Washed durable granular material
Effective size	0.5–1.0 mm
Uniformity coefficient	<3.5
Depth	24–36 in.
Underdrains	
Material	Perforated plastic pipe, 4-in. diameter
Slope of underdrain	0.5–1.0%
Bedding	Washed durable gravel, ¼–1½ in. size graded bedding with small-size gravel on the top
Venting	Upstream end of filter bottom
Dosing	Complete 2-in. flooding twice per day Hydraulic loading rate 2.5 gpd/ft^2 May range from 0.75–15 gpd/ft^2
Distribution	Splash plates

maintain aerobic conditions. This is accomplished by intermittent flooding of the bed. As the applied flow percolates into the bed, air is drawn in, replenishing the consumed oxygen.

Figure D.11 shows a typical buried intermittent sand filter installation that is applicable for use at a single-family residence where a surface discharge is required. The filter follows the septic tank. Provisions must also be made for disinfection by chlorination, prior to discharge. Intermittent sand filters can be buried, covered with a means of access, or left open to the atmosphere. In colder climates, protection against freezing is required. The buried filter may employ rock distribution of the influent, similar to the design used for a mound bed. The rock layer will support a soil cover. Otherwise, a covered filter could be constructed similar to the recirculating filter shown in Figure D.12.

Figure D.12 shows a typical flow diagram for a small recirculating intermittent sand filter. Flow from the pretreatment septic tank is piped to a wet well/dosing/recirculation tank. The tank is sized to provide a 2-inch flooding of the filter. Figure D.12 shows a splash plate located at the filter center for distributing the flow without eroding the sand. The filter effluent piping is routed through the dosing tank, where a float valve permits the flow to fill the dosing tank before any flow is discharged. Recirculation permits higher daily hydraulic loading to the filter without increasing the organic load, with some installations being dosed as often as every 30 minutes. This improves filter performance by drawing more air into the filter with the more frequent dosing. Non-recirculating filters are generally designed for two dosings per day when septic tank effluent is applied because of the higher organic strength of the wastewater.

The engineer should always consider an intermittent sand filter where a surface discharge is required for a small wastewater flow. The BOD_5 (BOD for first five days at 20°C) and the suspended solids of the filter effluent are each normally less than 10 mg/L. Most of the nitrogen is oxidized to nitrates. When properly designed and operated, reliable treatment is achieved with little maintenance being required. As with all wastewater, disinfection is required prior to discharge. As discussed previously, the simplest means of accomplishing disinfection for small flows is by use of a tablet chlorinator.

The permitting authority may impose restrictions on the area surrounding a surface discharge for health and safety purposes, including the following:

- When discharging to a point providing a dilution of less than 10 to 1, direct human water contact should be restricted by ownership or easement of the flow path downstream for 500 feet.
- When discharging to a dry ditch or to an intermittent stream, the channel slope should be greater than 1 percent and ponding should not be permitted.
- Where two or more discharges are to the same dry or intermittent flow channel, the discharge points should be more than 500 feet apart.
- Where subdivisions require a surface discharge, a single treatment plant and discharge point is recommended instead of individual systems. The engineer should review the applicable local and state regulations.

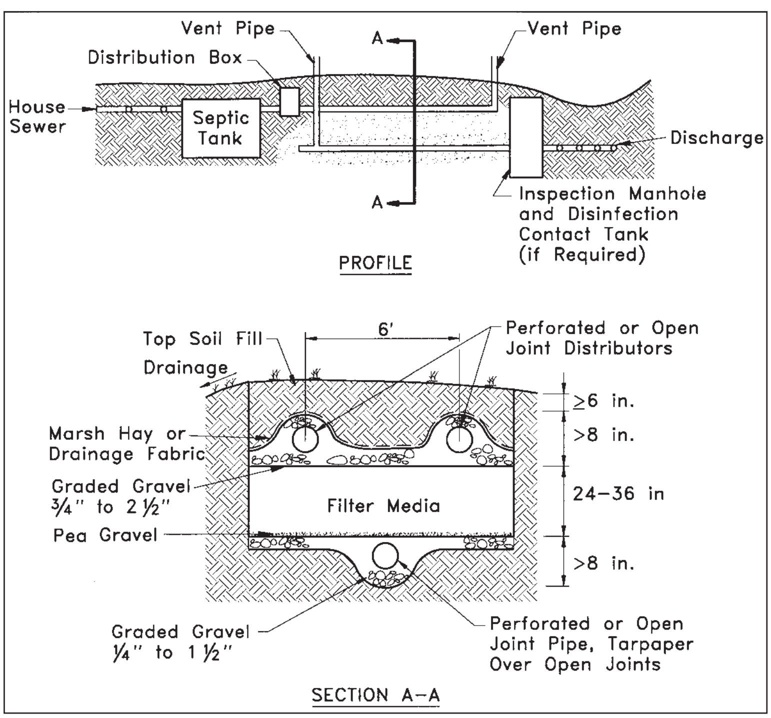

Figure D.11 Typical buried intermittent sand filter. (U.S. EPA, 2002)

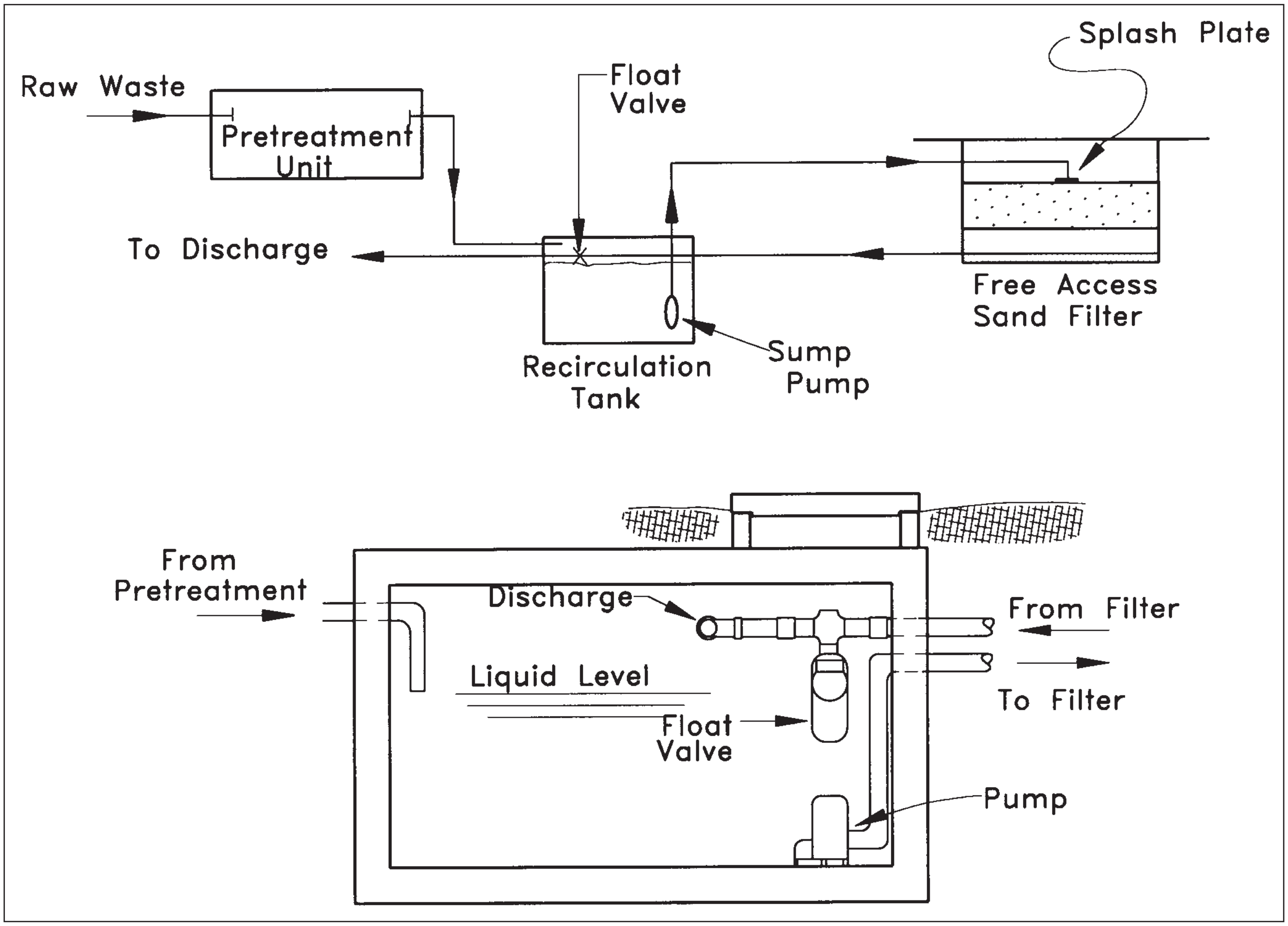

FIGURE D.12 Typical recirculating intermittent sand filter. (U.S. EPA, 2002)

SMALL COMMUNITY WASTEWATER TREATMENT

General Information

In those instances where a developer elects to construct one central wastewater treatment facility to serve the needs of the development, there are a number of technologies available. The more suitable of the technologies employ aerobic (in the presence of oxygen) systems for the decomposition and stabilization of the waste.

Theoretically, the end products of aerobic decomposition are carbon dioxide and water and a small quantity of salts. In reality, there is a significant fraction of all organic matter that is refractory to oxidation. This is the organic residual found in topsoil and stable forms of humus. Since the normal aerobic process is never continued for a sufficient period to accomplish complete oxidation and because of the presence of the refractory component, there is always a residual called *sludge* that must be disposed. The stability of this sludge depends on the conditioning process employed.

Aerobic processes employed in the treatment of small flows are of several types, including fixed film and suspended growth processes. With both the fixed film and the suspended growth processes, the organic constituents in the wastewater are adsorbed and absorbed by a biological growth. These organic constituents are then used by the microorganisms in the biological mass as an energy source and for growth. With the fixed film process, biological growth is supported on an inert surface. The biofilters discussed earlier as a suitable means of treating wastewater from an individual home are a type of fixed film reactor. An early form of a fixed film process that has been widely used in wastewater treatment is the trickling filter, which was originally a bed of rock with the rock surfaces supporting the fixed film growth. Various plastic forms are now available, and these have largely replaced the use of rock in the beds because better circulation of air is achieved and a greater surface area per unit volume is provided. Another form of fixed film support is the rotating biological contactor, where discs are mounted on a rotating shaft. As the shaft is rotated, the discs alternate between being submerged in the liquid and being exposed to the air, where oxygen is available. Air may also be added to the flow and used to assist with the rotation of the discs. These processes must be followed by final clarification and disinfection. In addition, the sludge from the clarification process must be processed. Dewatering and air drying on a small sand bed is one method of handling this sludge. Also common for treating small flows are aerated and facultative lagoons.

The suspended growth aerobic process is more common to all wastewater treatment, including small flow treatment. A variety of designed package units are available for use as a means of providing on-site treatment. All aerobic suspended growth processes (commonly called *activated sludge*) include a contact chamber, where the incoming flow is mixed with a biological population. The term *mixed liquor* is used to describe the combination of the incoming flow and the biological population. The solids that are within the mixed liquor suspension are called *mixed liquor suspended solids* (MLSS). The mixed liquor is agitated by aeration to supply oxygen and to prevent separation of the biomass from the mixed liquor. Diffused air is usually used to accomplish both mixing and aeration. This period of aeration and mixing is usually 24 to 48 hours for small systems, and the process is called *extended aeration.* During this period, the organic material is oxidized and converted to cell mass. The increase in cell mass is 30 to 50 percent of the BOD added to the system. Therefore, biomass (waste activated sludge) must periodically be removed from the system. In the most commonly used aerobic processes, the residual biomass is relatively stable and can usually be spread on land. However, air drying beds or other disposal means may be required at many locations. A local wastewater treatment plant may take the sludge for stabilization. In addition, the local facility for treating septic tank sludge may be a suitable means of disposal.

Effective biological treatment depends on keeping the biomass in a proper physiological state, whereby the biomass can be separated by gravitational settling, producing a clarified effluent. The level and method of feeding largely determine the physiological state of the biomass. The level of feeding or *food-to-microorganism ratio* (F/M ratio) is controlled by adjusting the concentration of the biomass to the feeding rate. The biomass is expressed as the concentration of the MLSS in milligrams per liter, and the feed rate is the BOD in milligrams per liter in the incoming flow. Some operating parameters for extended aeration systems are given in Table D.7. The normal per capita contribution of BOD_5 is 0.17 lb/day, and for single-family dwellings the per-bedroom contribution may be taken as 0.4 lb/day. The activated sludge process is stable and produces a high-quality effluent when properly designed and operated. The process is subject to upset, resulting in poor removal of BOD and suspended solids or poor separation of the mixed liquor from the flow in the clarification process, producing a poor-quality effluent in either instance. The extended aeration process is relatively stable. Where a proper F/M ratio, oxygen level, and mixing are maintained, few problems should develop. The dumping of excessive amounts of cleaning agents or other toxic agents into the sewer where on-site treatment is practiced may cause failure of the process.

It is common for small treatment units to be of the package type, as it is not economical to design and construct an on-site system in place where the daily flow is less than 200,000 gallons. Most suppliers of smaller units, such as those with less than 10,000 gpd capacity, have the product tested and performance-certified. The National Sanitation Foundation (NSF) provides this service, and the local permitting agency may require data of this type. When a package unit is specified, catalog data will provide the needed design information. All design conditions as shown in Table D.7 will be available from manufacturers' literature.

Another variation of the activated sludge process that is suitable for use in large residential developments is the

TABLE D.7 Operating Parameters for Extended-Aeration Processes for Small On-Site Units

Parameter	Average Parameter
MLSS, mg/L	2000–6000 (5000–6000 common)
F/M Ratio, lb BOD per day/lb MLSS	0.05–0.1
Solids retention time, days (related to F/M)	20–100
Hydraulic retention time, days	1–5 (1.5–2.0 common)
Dissolved oxygen, minimum level in mg/L Discharge oxygen concentration generally	>2.0 >5.0, so unit should carry this level
Energy input for mixing, Hp/1000 ft^3 Energy input is usually by diffused air.	0.5–1.0
Clarifier overflow rate, gpd/ft^2	200–400
Clarifier solids loading, lb/d/ft^2	20–30
Clarifier weir loading, gpd/ft of weir	10,000–30,000
Sludge wasting frequency, months	6–12

Note: Design parameters of "package units" controlled by the manufacturer.

sequencing batch reactor (SBR). This modification was initially marketed as concrete tanks connected in series. The precast tanks could be delivered to the plant site, placed on a suitable foundation, and connected with piping. A benefit of this modification was that additional tanks or an additional treatment train could be added as more capacity was needed. A later modification to this design alternative called for the placement of two tanks in parallel.

For most subdivision SBR systems, two reactors are sufficient. Raw wastewater, following screening and grit removal, is split between the basins with a valve located in the influent line to each of the two reactors. Those valves are useful not only for flow control but also for isolation of either unit for maintenance. Each reactor moves through four stages to accomplish treatment: (1) filling (aeration is provided during the filling stage), (2) aeration, (3) settling, and (4) decanting of clarified flow (see Figure D.13*a*). Under normal conditions the entire cycle is completed in four hours (see Figure D.13*b*). Note that the flow is aerated for two hours after filling is complete. The aeration period is followed by two hours of settling and a two-hour decant period. The process is then repeated. As shown by Figure D.13*b*, the influent control valves are timed to fill and aerate one unit while the other is in the settling and decant mode. Note that the design shown includes a baffle that is located to provide two zones in the reactor. The initial zone is termed a *pre-react zone* and the remainder of the tank is termed the *main react zone*. The influent flow to the reactor is mixed with the consolidated biomass, providing for rapid uptake of the organic constituents in the pre-react zone. There is no additional feeding of the biomass in the main react zone. This is an effective means of promoting the growth of a desired zoogleal biopopulation while minimizing the growth of filamentous bacteria. The pre-react zone is normally 10 to 15 percent of the total basin volume. Sludge is wasted from the underflow near the end of the decant period. Disinfection facilities must be provided following the reactor.

The sequence timing for the process, as shown in Figure D.13*c*, can be adjusted to accommodate higher inflow rates, such as may occur during wet periods (high inflow during wet periods should not be a problem with a system serving a new development). The process is a modified plug flow operation. High-level secondary treatment and nitrification can be accomplished. Note that the entire biological process and clarification occurs in a single tank.

Nitrogen and phosphorus removal can also be accomplished as a part of the process by control of the aeration process (see Figure D.13*d*). The aerobic phases promote nitrification and phosphorus uptake. The air is turned off to create an anoxic phase, which accomplishes denitrification and phosphorus release. Note that nitrogen and phosphorus control is covered in more detail in a later section.

While the batch reactor eliminates the need for a secondary clarifier and the associated valving and piping, the plant design must include facilities for grit, screenings, and waste sludge.

Membrane Bioreactors. The membrane bioreactor technology combines the activated sludge process with a membrane system to provide organic and suspended solids removal. Submerged membranes replace the clarification unit in the traditional activated sludge process and are capable of producing an effluent with much lower turbidity and suspended solids concentrations than conventional treatment systems. Prefabricated and preengineered units are available in either concrete or steel tank construction, with treatment capacities starting around 5000 gpd. See Figure D.14.

Membrane bioreactors are preceded by screening. The flow then enters an anoxic chamber to promote the removal of nitrogen. The forward flow from the anoxic zone proceeds to an aeration chamber, where oxygen is added for biological respiration and mixing. The effluent from the aeration chamber then moves to a third chamber housing the submerged membranes that separate the suspended solids from the mixed liquor. The use of membranes for clarification allows the biological portion of the process to operate at much longer sludge ages and higher MLSS concentrations than conventional activated sludge processes. This in turn promotes a more stable operation, complete nitrification, and reduced sludge production. The high MLSS concentrations also reduce the tank volume required to 30 to 50 percent of a conventional activated sludge process. Like all biological processes, the plant design must contain provisions for the removal and disposal of waste sludge.

There are a multitude of equipment manufacturers that produce membrane bioreactor systems. The engineer contemplating the use of such a system should investigate those available in the marketplace, as the ultimate selection should be made following the careful consideration of the final effluent requirements, ease of maintenance and operation, energy costs, and the initial capital cost of constructing the facility.

Stabilization Lagoons (Ponds). This wastewater stabilization process may be considered for serving residential developments where sufficient land is available for the lagoon system and the required buffer. Buffer requirements vary, based on local conditions. The severity of winter conditions largely determines the potential for odor problems and buffer needs. A buffer requirement of up to 500 feet is not uncommon. A 500-foot buffer establishes a plant site of 5 to 7 acres. The principal advantages of a lagoon system are the reliability of treatment and the low operational requirements.

The two types of lagoon designs that are applicable for small systems are the aerobic and the facultative lagoons. Wastewater treatment can be accomplished in temperate climates when employing a lagoon system without creating an environmental nuisance (malodors, etc.) because of the symbiotic conditions maintained between algae growth and bacterial decomposition. In the presence of sunlight and with the availability of nutrients that are provided by the wastewater, the following biological reactions occur:

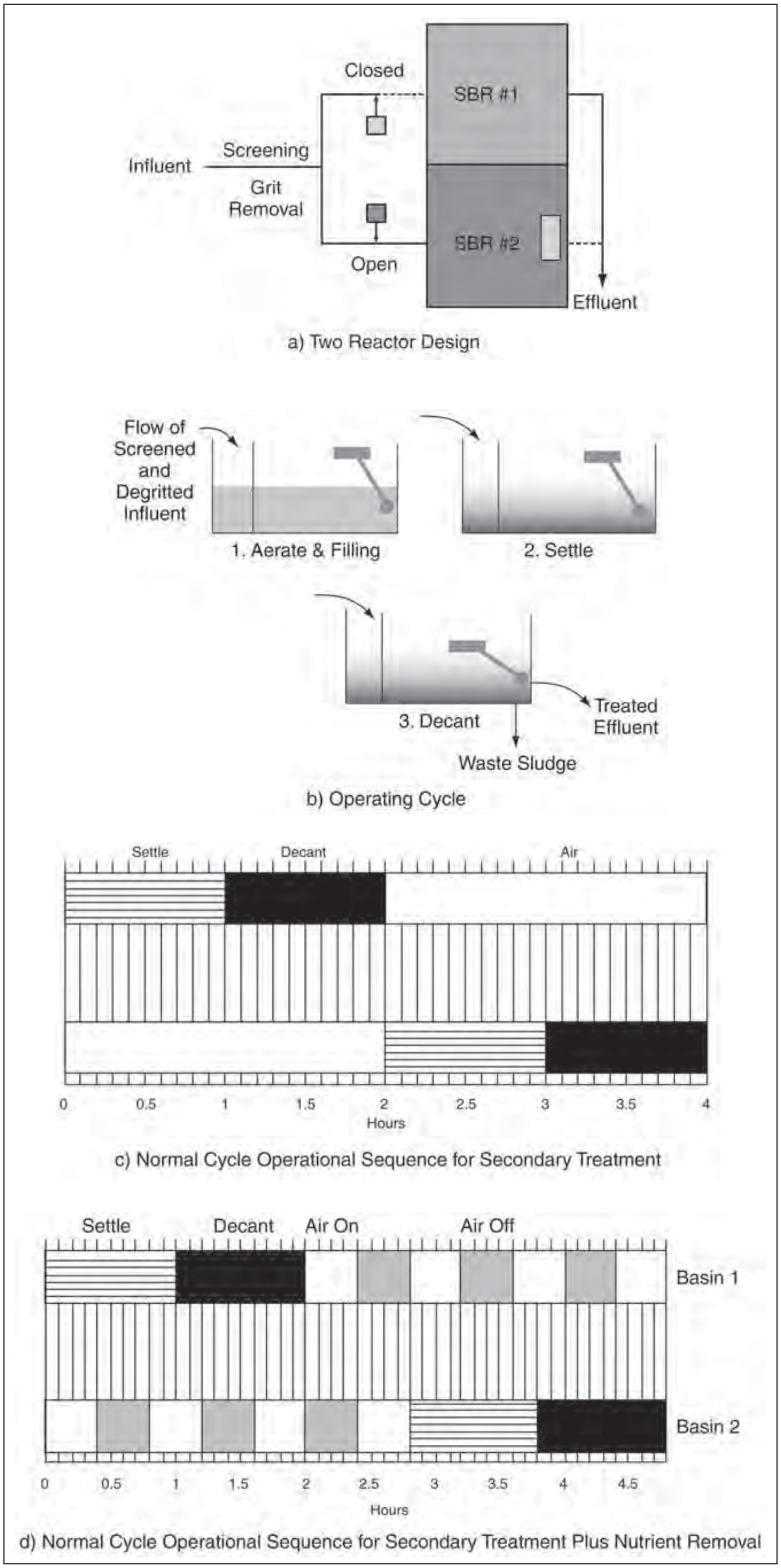

FIGURE D.13 Batch reactors

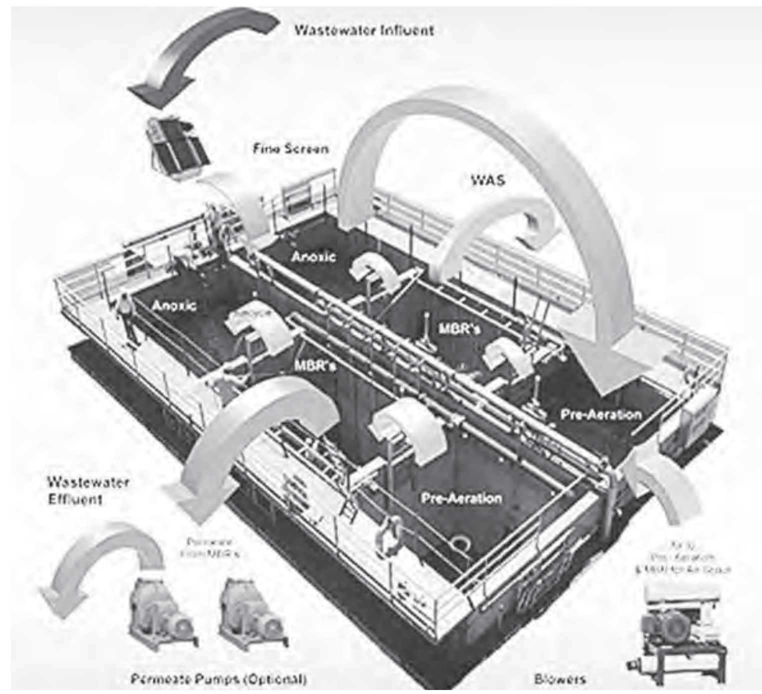

FIGURE D.14 Membrane bioreactor.

Autotrophic reaction:

$$\begin{aligned} &CO_2 + H_2O + N, P \text{ and trace elements} + \text{Sunlight} \\ &= \text{Algae cells} + O_2 \end{aligned} \quad \text{(D.1)}$$

Hetertrophic reaction:

$$\begin{aligned} &\text{Organic matter} + O_2 + \text{Bacteria} \\ &= CO_2 + H_2O + N, P, \text{and trace elements} \end{aligned} \quad \text{(D.2)}$$

In an aerobic lagoon, sufficient mixing and aeration must be provided to keep the solids suspended and to provide free oxygen throughout the lagoon depth. The completely aerated lagoon is not common. Most lagoons are facultative in terms of biological activity. In the facultative lagoon, the only mixing that occurs is from surface wind action and from thermal density currents. Thus, there are two zones in the facultative lagoon. The top 2 feet or so contains algae growth and is generally supersaturated with oxygen from midmorning until late afternoon. This top layer serves as a cap over the facultative and anaerobic activity occurring at the lower depths and in the bottom sludge. Malodorous gases and reduced compounds, such as ammonia and sulfides that are released into solution by the anaerobic activity in the bottom sludge, are oxidized to such stable compounds as CO_2, sulfates, and nitrates as they reach the top layer.

When lagoons are operated at northern latitudes, where an ice cover exists for weeks during the winter, the biological activity is reduced and the lagoon becomes septic throughout its depth. When the spring thaw comes, the septic gases are released to the atmosphere, causing a severe odor problem that may last for several weeks. A similar condition, though less severe, may occur where the winter water temperature drops to near freezing for several weeks and decomposition is slowed to where organic sludge accumulates under septic conditions. When the water temperature rises in the spring, the release of septic gases may exceed the solubility of the lagoon contents, releasing malodorous gases to the atmosphere.

Most states have regulations for the siting and design of lagoon systems. Retention times may vary from 10 to 15 days for the complete aerobic operation in temperate climates to more than 120 days for a facultative lagoon located at a northern latitude. The engineer should obtain information on design requirements in the state where the lagoon will be located. The information in Table D.8 is provided as general guidelines for lagoons located south of the thirty-eighth parallel of latitude.

Pond depth is limited to more than 4 feet to discourage bottom-rooted plant growth. The depth should be kept as shallow as possible to obtain the benefit of mixing from wind action at the surface and to limit the facultative zone. The lagoon side slopes should be uniform and constructed to the proposed grade. The cells must be watertight below the waterline. Plastic curtains are suitable for cell division barriers. A loop is formed at the top and bottom of the sheet plastic. This loop is used to hold the flotation material at the top of the sheet and a chain at the bottom. The chain rests firmly on the bottom to prevent movement from wind action. A window is cut in the plastic to permit flow between cells.

TABLE D.8 General Guidelines for Lagoons South of the 38th Parallel	
Pretreatment	Screening to remove floatable solids
Detention time	30–40 days
Water depth	4–6 ft
Number of cells	3 in series 50% of volume in first cell 30% of volume in second cell 20% of volume in third cell
Side slopes	3 horizontal to 1 vertical (3:1)
Cell bottom	Level
Inlet pipe—outlet at center of first cell to prevent solids buildup near the side slopes	
Fence to prevent access to lagoons—post notices around fence of polluted water	
Landscape site, including side slopes for easy mowing	
Lighting—should be sufficient to enable a trespasser to be aware of the environment	

Most of the heterotrophic activity occurs in the first cell, with the second and third cells providing polishing treatment. The second and third cells—and if the system is not heavily loaded, all three cells—should develop a cover surface of duckweed. This is desirable for the third lagoon, as suspended algae growth is essentially eliminated beneath the surface growth, producing a better-quality effluent.

It is recommended that some mechanical mixing and aeration be provided for all lagoon operations. There are several suppliers of excellent floating aerators that provide mixing with a small impeller and aeration by induction along the shaft. These can be low-horsepower units located to encourage a low level of circular flow in each cell. This minimizes sludge buildup and materially improves treatment performance.

Final clarification has become common with lagoon operations. Clarification is needed to reduce the algae concentration in the effluent. Clarifier design is the same as that which is used for extended aeration treatment. It is recommended that the surface loading be in the range of 400 to 500 gpd/ft^2. Disinfection is also required with the tablet chlorinator being acceptable. Liquid chlorine feeders are also suitable. The use of ultraviolet (UV) disinfection eliminates the need for a chlorine contact vessel and dechlorination.

Disinfection

Biological treatment does not eliminate all enteric organisms. Therefore, enteric pathogens are assumed to always be present. The three principal pathogenic forms found in wastewater are bacteria, viruses, and amoebic cysts. No routine direct test is made for pathogens, but tests are performed to determine the presence of the enteric coliform group of bacteria, which are always present in sewage in great numbers. If this group has been eliminated, it is assumed that the pathogens have been eliminated.

Chlorine Disinfection. Disinfection can be accomplished by heat, chemicals, or radiation. Wastewater disinfection is usually accomplished by the use of oxidizing chemicals or by radiation. Chlorine is the most common chemical employed for disinfection at larger installations. Chlorine is plentiful and relatively inexpensive and the technology and equipment required for its use are well developed. Chlorine is available as a liquid, a solid, and a gas. Liquefied gas is available in 150- and 2000-pound containers. Chlorine gas is a very strong oxidizing chemical and very dangerous if not properly handled. The gas form was used in World War I. In wastewater treatment, the gas is evaporated off and dissolved in water, with the solution being fed into the wastewater. The water solution is similar to household bleach. Household bleach is a 5.25% sodium hypochlorite solution that is available in plastic containers. Stronger industrial hypochlorite solutions are available for use at smaller treatment plants. Chemical feed pumps are used to meter the hypochlorite solution into the wastewater. Calcium hypochlorite is available as a tablet or in granular form. The tablet form is fed by means of the tablet chlorinator, as shown in Figure D.10. Figure D.15 shows a typical tank-mounted chlorination feed system. Water flow through the eductor is required to produce a vacuum at the feed controller mounted on the 150-pound chlorine cylinder for chlorine to be released from the cylinder.

When chlorine reacts with water, hypochlorous acid or the hypochlorite ion is formed, as shown in the following

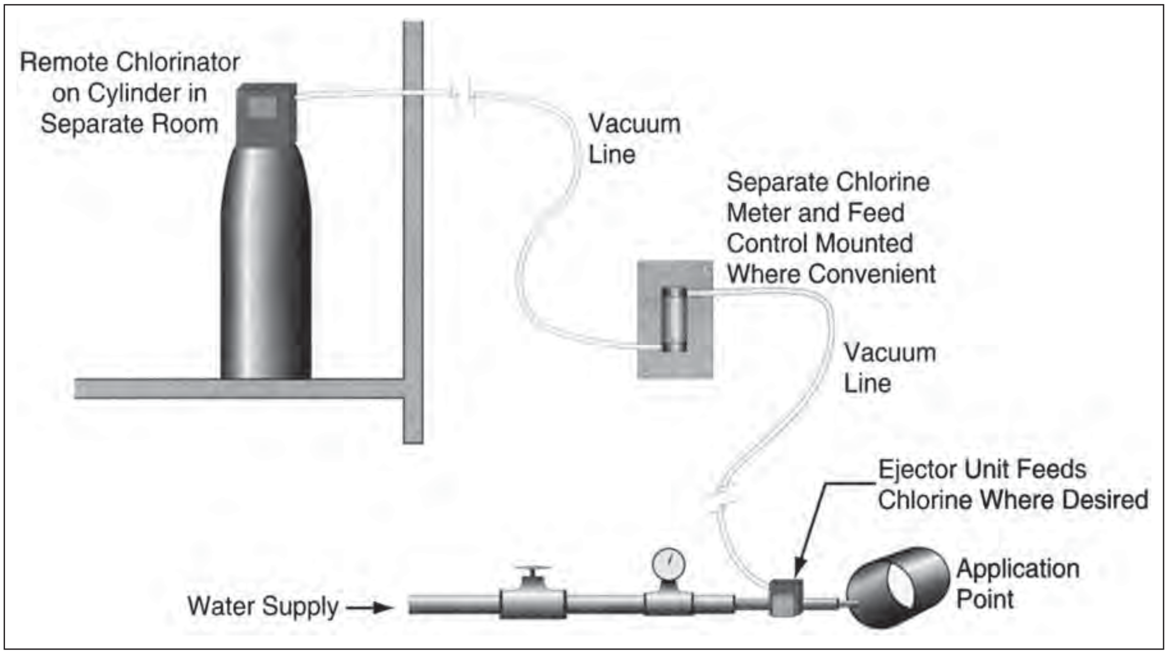

FIGURE D.15 Typical vacuum chlorine feed system.

equations. All three reactions produce the hypochlorite ion, which in the presence of water will be in equilibrium with the hypochlorous acid form. Chlorine gas tends to decrease the pH, whereas the hypochlorites tend to increase the pH of the water. However, sewage is normally fairly well buffered and the amount of chlorine added has little effect on the pH. The equilibrium between the acid and the ion forms depends on the pH of the water, with the acid form predominating at a pH below 6.3. The acid is the most active disinfecting form but no attempt is made to adjust the pH to optimize disinfection.

Chlorine gas reaction:

$$H_2O + Cl_2 \leftrightarrow H\,O\,Cl + H^+ + Cl^- \qquad \text{(D.3)}$$

Sodium hypochlorite:

$$H\,O\,Cl \leftrightarrow O\,Cl^- + H^+$$

Hypochlorous Acid — Hypochlorite Ion (D.4)

$$Na\,O\,Cl \leftrightarrow Na^+ + O\,Cl^-$$

Calcium hypochlorite:

$$Ca(O\,Cl)_2 \leftrightarrow O\,Cl^- + H^+ \qquad \text{(D.5)}$$

Chlorine reacts with most any electron donor to form a chloride. The oxidizing chemical reacts with organic matter in the wastewater, including bacteria and viruses. It also reacts with nitrogen compounds such as ammonia to create a combined form of chlorine that has disinfection capability. The first reaction forms a monochloramine.

$$N\,H_3 + H\,O\,Cl \leftrightarrow N\,H_2Cl + H_2O \qquad \text{(D.6)}$$

Monochloramine

There is sufficient ammonia in most wastewater to react with all the added chlorine. Therefore, only the combined form of chlorine is normally found in wastewater. If enough chlorine is added, dichloramines and trichloramines (toxic gases) may be formed. This quantity of chlorine would not normally be added to sewage.

Disinfection with chlorine is a time-concentration process. Therefore, the chlorine solution must be well mixed with the wastewater and a contact period must be provided. The combined form is not as strong an oxidizing agent as the free forms. This decrease in effectiveness is overcome by increasing the dosage of chlorine and/or by increasing the contact time. Wastewater disinfection requirements are usually based on a 30-minute contact time with a 3.0-mg/L total chlorine residual at the end of the contact period. The chlorine dosage for secondary wastewater is usually about 10 to 12 mg/L to provide the 3.0 mg/L residual. One mg/L is equal to a dosage of 8.34 pounds per 1,000,000 gallons of wastewater.

Ultraviolet Radiation Disinfection. Figure D.16 shows a typical UV disinfection design. Whereas a chemical disinfectant dose is determined by residual concentrations times a

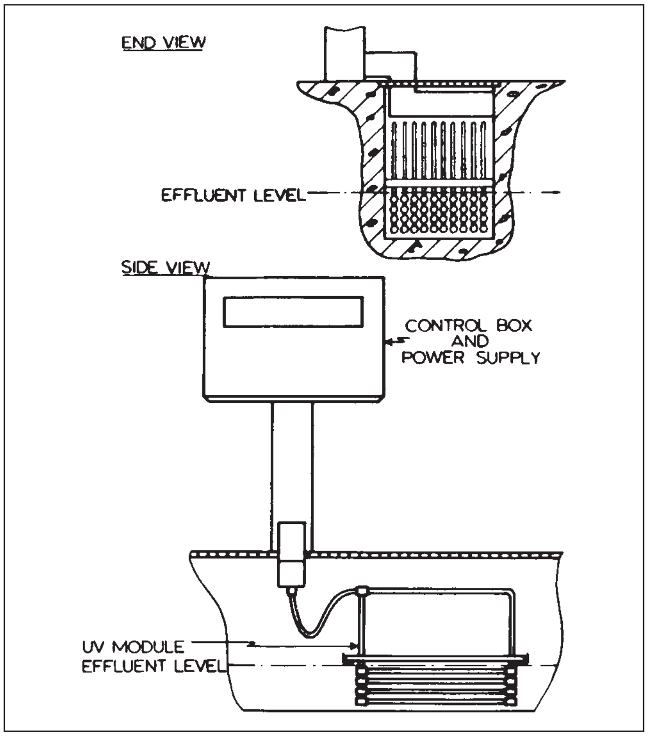

Figure D.16 Ultraviolet disinfection unit.

contact time (in minutes), UV dose is determined by UV intensity times exposure time (in seconds). The equipment provides for typical water quality 8 seconds of contact time in the unit where the UV intensity is greater than 4000 microwatts per square centimeter ($\mu W/cm^2$), to give a dose of 32,000 $\mu W\text{-}sec/cm^2$. A quartz tube protects the UV lamps, with the entire assembly being removable for cleaning.

Ultraviolet radiation with conventional UV technology is an effective means of disinfection that is suitable for tertiary- and secondary-quality effluents. UV equipment is designed to provide sufficient radiation to accomplish disinfection in a flow-through reactor. This method of disinfection should be considered the preferred means for use at small treatment plants. When UV disinfection is used, sampling for BOD and bacterial counts should be from the equipment discharge. If samples are collected at the plant outfall, the effluent will have been reseeded from the film on the effluent conduit, which can yield very misleading test results. This is particularly true for effluents having an ammonia residual, as the reseeding will likely include nitrifiers, leading to nitrification in the BOD bottle.

Treatment Plant Considerations

When a central facility is needed for wastewater treatment, the engineer should conduct a study to determine the availability of capacity at existing plants. Routing the flow to an existing treatment plant where possible is preferred to the construction of a new plant to serve an individual development. The unnecessary proliferation of small plants is not an environmentally sound practice. The cost of treatment will generally be less at a larger facility.

When a decision is made to construct a new plant to serve an individual development, a determination must be made on the plant capacity; the site location; level of treatment required and the treatment process to be employed; who will own, operate, maintain, and control the completed facility; and how the construction cost will be funded. Principal items related to these considerations include the following.

Treatment Plant Capacity. A permit to construct and operate a new plant comes under the authority of both state and local government. These agencies, together with the local planning and zoning departments, must be consulted about zoning, plant location, area to be served, and total population to be served. The projected growth of the proposed service area should be coordinated with the local planning department staff. The initial design capacity is generally based on the area needs for a period of 15 to 20 years. In most instances, land should be set aside for future expansion and provisions made in the design to accommodate any projected expansion. There may be instances where the treatment facility will be designed solely to serve a single development, but this will generally not be the case if the local government has developed a comprehensive plan. It is incumbent upon the engineer to ensure that suitable planning precedes the location and sizing of a new plant.

Plant Site. A suitable discharge point must be available. It is generally preferred that the plant be located adjacent to the discharge point, but it is not a requirement. The plant must be protected against the 100-year flood elevation. Suitable buffering of the site from the surrounding community must be provided. Buffer requirements generally specify that a plant be sited several hundred feet from the nearest residence. An all-weather road must be provided to the plant site. Additionally, a reliable water supply and three-phase power must be provided. Local zoning, or a zoning variance, must be obtained for the intended land use. Downstream water uses, such as an existing public water supply intake, a public recreational site, a shellfish harvesting area, or other water quality considerations may eliminate a potential site or discharge point from further consideration.

Level of Treatment. Treatment requirements depend on several factors, including the classification of the receiving water, the dilution provided by the receiving stream (generally based on the 7-day, 10-year low flow), and the hydraulic features of the stream related to mixing and reaeration, such as slope, depth, type of stream bottom, and downstream conditions. The level of treatment required is established by the state water pollution control agency, but in all cases, secondary treatment is required as a minimum by federal law. The state agency having jurisdiction for permitting wastewater treatment plants may conduct a site-specific field study of the receiving water body to establish the assimilative capacity or require the engineer to conduct the study prior to establishing the treatment requirements. Most states only issue a discharge permit to a public agency. In this case, arrangements must be made with the agency that will own and operate the plant before starting design, as the operating agency may have specific design requirements.

Funding of Construction and Operation. The local government is unlikely to participate in funding the construction of a new plant unless it will meet a regional need. If the area has been planned for sewer, some level of cost participation may be arranged, and the willingness of the developer to assist with the cost may expedite the construction program. Otherwise, the developer may be faced with providing the entire funding for the plant construction. Operating costs should come from a service fee. The fee for sewer service should cover amortization of construction costs, operation and maintenance costs, a replacement fund, and general administration costs. The construction cost is often prorated to each building unit served and collected as a part of the cost for a construction permit.

An environmental assessment is required for the selected plant site. After the engineer has completed a preliminary investigation covering at least the four subjects already presented and found that the selected site is, in general, acceptable, an in-depth environmental assessment is prepared and copies of the report presented to the local and state authorities. A presentation at a public hearing, which is generally held as part of the approval process, is often required. The environmental assessment includes a thorough investigation of the esthetic, ecological, physical, and social aspects of the proposed project. General potential impacts associated with the construction and operation of a wastewater treatment plant include lighting at the plant, neighborhood aesthetics, noise, odor, traffic, and air pollution. These impacts can be mitigated through good design and operation.

Process Design

While the geometric design, piping, and operating procedures may vary, the following unit operations and processes are common to all wastewater treatment plants:

- Screening and/or comminution
- Grit removal (not always practiced in small plants except in some plants located near a coast, where sand is a problem)
- Flow measurement
- Lift station
- Activated sludge process
- Clarification with return sludge
- Disinfection
- Sludge wasting

The hydraulic components such as all piping, pumping, channels, or other flow-carrying items are designed to pass 2.5 times the plant design capacity. The hydraulic capacity may be higher if the plant is designed to handle large infiltration and inflow volumes or where the plant is subject to higher than normal peak flows associated with the service area. The aeration reactor is designed based on the average daily design flow. Clarifiers, contact tanks, and so on, must be designed to treat the peak flows so as to provide the required loading and/or retention time. Figure D.17 shows a generalized flow diagram for an activated sludge treatment plant.

Screening. Screening is provided to remove large particles that are not amenable to treatment along with the other constituents of the wastewater flow. If a comminutor is provided, a bypass screen is included for use in case of mechanical failure of the comminutor. Screening will remove 1 to 5 percent of the incoming BOD.

Flow Measurements. Flow measurement location may depend on local or state requirements. An effluent flow measurement, which is the flow being discharged, is generally required by the permit conditions, but some engineers and operators also like to have a record of incoming flow. The designer must use care to ensure that no recirculated flow is returned ahead of the influent flow-measuring equipment. Ultrasonic meters that measure the depth through a control section are preferred. The flow measurement data is transferred to a totalizer and a chart, with the data being included in the daily records. Figure D.18 shows a typical installation of an ultrasonic meter in a manhole. The Palmer-Bowlus flume is grouted into the manhole bench, forming the flow-through channel.

Pumps. Sewage pumps are normally sized to pass 2.5 times the average design flow. Submersible pumps are recommended, because at small plants there is generally only one operator present, and the design should not include any equipment that requires below-ground maintenance. Solid-state frequency controllers for varying the pump rotational speed to match the pumping rate to the incoming flow rate should always be considered. This modification eliminates surging through the plant, which is normally associated with pumps that cycle on and off. Two pumps should always be provided, with each pump having a pumping capacity equal to 2.5 times the plant design capacity. The pump design and selection should always provide the required peak-pumping rate to be available, even with the largest pump out of service. Automatic alternation of the lead pump is needed to ensure that each pump is subject to daily operation.

Activated Sludge Process. The extended aeration process is designed to provide 24 hours of aeration. At plants having a capacity of less than 40,000 gpd, one aeration chamber is usually provided. Where only one tank is provided, maintenance of all components must be possible without dewatering the tank. This means that the diffusers must be mounted for removal and replacement from above the water surface. Plug flow tanks are generally long, rectangular chambers

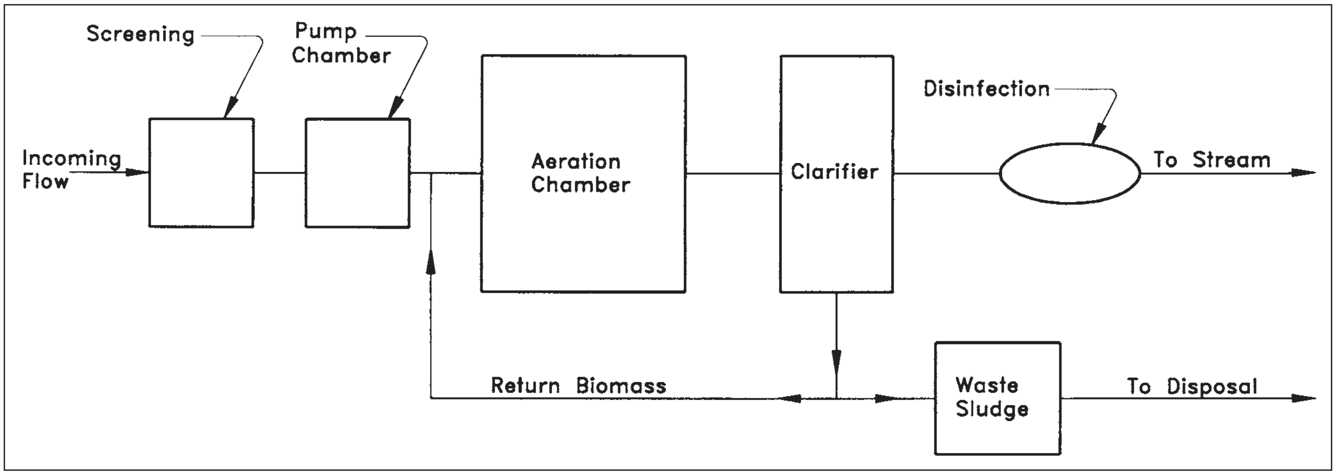

FIGURE D.17 Typical activated sludge flow diagram.

where there is little longitudinal mixing. The flow is injected at one end of the tank and moves through the tank to the effluent end. The return sludge flow is mixed with the incoming flow at or near the entrance to the aeration tank. The aeration is achieved by passing compressed air through diffusers located approximately 1 foot off the bottom of the tank. Normally, the diffusers are located across the tank bottom in rows transverse to the direction of wastewater flow. This alignment reduces short-circuiting and provides for good mixing of the contents. Table D.9 provides a summary of design criteria for the activated sludge process treating domestic sewage.

Aeration is required in order to provide mixing of the tank contents, which keeps the biomass in contact with the wastewater and allows for the transfer of oxygen to the flow. Oxygen is transferred from the rising bubble surfaces as well as from the surface renewal that results from the pumping action of the rising bubbles. The smaller the bubbles, the greater the surface area of transfer (per unit volume of air introduced). Fine or medium bubble diffusers are recommended because of the more efficient oxygen transfer, and the mixing pattern is superior to that of coarse bubble diffusers. Manufacturer's literature indicates that some of the fine bubble diffusers have a transfer efficiency of 15 to 20 percent. The aeration equipment should be installed in accordance with catalog data.

Compressed air may be provided by either a centrifugal or a positive displacement blower. Small plants usually use

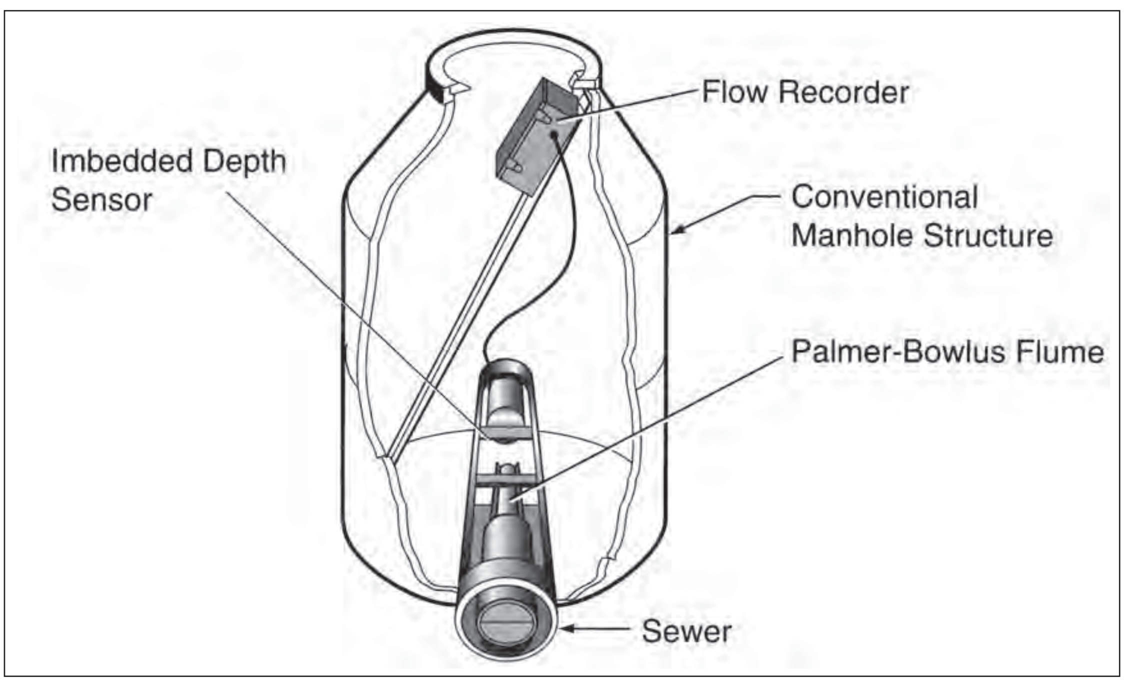

FIGURE D.18 Ultrasonic flow meter installation. (U.S. EPA, 2002)

TABLE D.9 Summary of Design Criteria for the Activated-Sludge Processes

Parameter	Conventional	Extended Aeration	Contact Stabilization	Oxidation Ditch
F/M (lb/day)/lb MLVSS	0.2–0.4	0.05–0.15	0.2–0.6	0.03–0.10
Sludge age	5–15	20–30	6–12	30+
MLSS in reactor	1500–3000	3000–5000	1200–3000	3000+
Sludge recycle ratio	0.25–1.0	0.75–1.5	0.25–1.0	0.25–1.5
Aeration time, hours	4–8, 6 normal	24–36	0.5	24+
Air, SCFM/lb BOD removed	500–1000	3000+	800–1200	N/A
MLVSS/MLSS	0.6–0.8	0.6–0.7	0.6–0.8	0.6–0.7

Note: All the secondary processes should remove more than 88 percent of the applied BOD. Regulations require that the BOD of the effluent be less than 30 mg/L. Most well-operated secondary treatments routinely produce an effluent having a BOD_5 between 10 and 15 mg/L.

the positive displacement blower because of cost. The positive displacement blower gives satisfactory service, but the air pressure vibrations associated with the operation result in a high noise factor. The noise is exacerbated at higher rotational speed. The engineer should specify a rotational speed of not greater than 1160 rpm.

Where the design flow is greater than 40,000 gpd, dual aeration tanks, with each having one-half the plant design capacity, should be provided. Conventional blowers provide air at up to about 8 lb/in^2 pressure. This is equivalent to 18.5 feet of water pressure. Oxygen transfer is related to the travel distance and size of the air bubble. Aeration tanks should be about 16 feet deep to obtain the greatest efficiency from the air compression operation. However, since most small plants are fabricated and painted before shipment to the site, highway restrictions limit the height and width of the tanks to 12 feet by 12 feet. A 12-foot by 12-foot tank would have at least 1 foot of freeboard, making a 40,000-gallon tank 40 feet long. The diffusers would be placed about 1 foot off the tank bottom, giving a 10-foot submergence depth. Plants providing capacities up to about 50,000 gpd are available as factory-assembled and painted units. Two units give a 100,000-gpd-design capacity.

Plants having a capacity greater than 100,000 gpd are usually field-erected. Package fabricated and field-erected plants are often circular for capacities greater than 50,000 gpd. The plants are shipped complete and ready for field assembly. A concrete base is poured in place, with the factory-supplied embedded section installed. The tank sections are erected by field welding or bolting. The circular shape is selected for structural strength and to minimize piping and pumping of the flow. The clarifier is located at the center of the unit. The aeration basin, waste sludge stabilization basin, and chlorine contact basin are generally located in the annular area outside the clarifier. Airlift pumps are used to transfer flow from one compartment to another. Figure D.19 shows a typical layout. The design shown is a contact stabilization process where a 30-minute contact period is provided (aeration of mixed liquor). The mixed liquor is then piped to the clarifier. The clarifier underflow of concentrated sludge is airlifted to the stabilization compartment, where it is aerated for 4 to 6 hours before being returned to the inlet to the aeration basin, where it is mixed with the incoming flow. The time periods used are based on plant design flow. All treatment processes are completed within the single unit, except for disinfection. Some designs also include a chlorine contact tank. UV disinfection should always be considered for small plants. The requirement for a contact tank and the need to store and handle chlorine are eliminated when UV disinfection is used. The sidewall depth of field-erected tanks is generally about 15 feet. See previous discussion of batch reactor design, as a common fabricated plant.

Clarifier Design. A clarifier having a surface area of less than about 200 ft^2 can be a hopper bottom design. Larger clarifiers must be designed to accommodate available equipment. The sludge collecting equipment, such as the drive and access bridge, must be selected from a supplier's catalog. The diameter is determined by the selected surface loading. It is suggested that a surface loading of 500 to 600 gpd/ft^2 be used. The depth will normally be 7 to 8 feet. The selected equipment determines the requirements for installing the inlet piping, effluent weirs, and sludge collecting equipment. The sludge recycling pumps and piping should have a capacity for returning from 25 to 150 percent of the plant design capacity. Scum from the clarifier should be piped to the sludge stabilization basin.

Disinfection. As noted previously, UV radiation should always be considered as a suitable disinfection means for small plants. This selection eliminates the need for a chlorine contact tank, but more important, the need for storage and handling chlorine is eliminated. The potential hazards associated with handling chlorine are a particular concern at small plants, where only one operator may be present. Another concern with chlorine at small plants is the need to

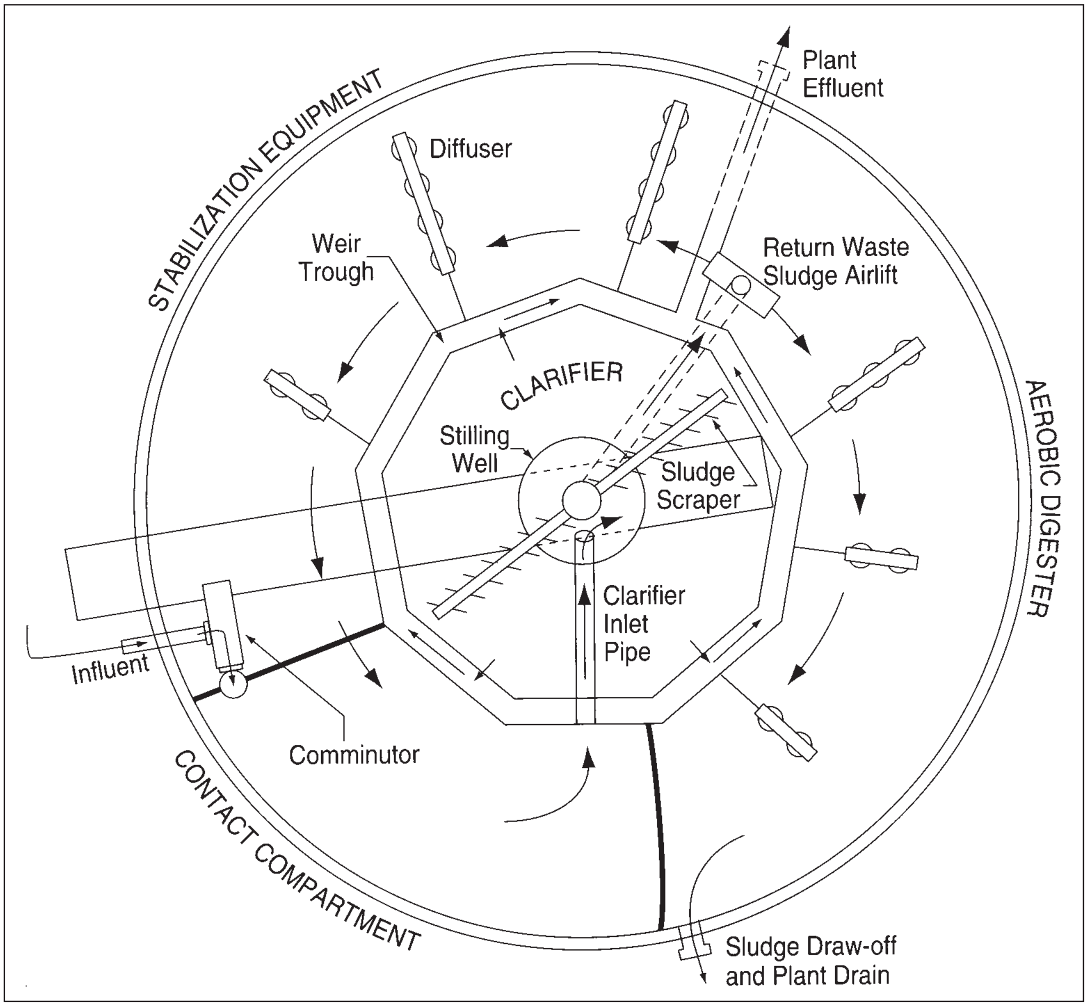

FIGURE D.19 Typical layout for the contact stabilization process. (U.S. EPA, 2002)

adjust the chlorine feed rate as the flow varies. The flow rate varies significantly at all plants during the 24-hour diurnal period, but the percentage of variation is greater for the small plant. Serious overdosing of chlorine will occur if equipment is not provided to automatically adjust the feed rate as the flow rate varies.

There is a minor potential hazard from UV light exposure to the eyes if caution is not exercised, but trained operators should not subject themselves to this hazard. The engineer should select proven equipment that does not require major disassembly for cleaning. Grease and slime accumulate on the tubes covering the lamps, reducing the UV light transmission. A strong phosphate detergent is required for tube cleaning.

Waste Sludge (Biosolids) Stabilization. Some local authorities may permit sludge from an extended aeration process to be disposed on land without additional stabilization. Normally, all waste activated sludge is subjected to additional stabilization by aerobic digestion. Stabilized sludge is a humus material that has a musty odor. It also may contain pathogens. When applied to land, soil texture and moisture-retaining capacity are improved. The sludge is also a low-level source of nutrients. The primary operation cost of aerobic digestion is the power costs for aeration and mixing. Self-cleaning, medium bubble diffusers are suitable for use in aerobic digesters.

Stabilization provides a reduction in the volatile suspended solids (VSS) and improves sludge compactability. The digester contents are consolidated by turning off the air and allowing the sludge to settle for 1 to 1.5 hours, after which the supernatant is decanted from the digester and returned to the aeration tank influent. The daily volume of sludge to be wasted from the clarifier return sludge piping depends on the solids content of the sludge. At a sludge yield of 0.5 and a plant influent BOD of 200 mg/L, the solids content of the waste sludge will be 834 pounds per million gallons of sewage flow. If the solids can be transferred from the bottom of the clarifier as a 1.5% solid (1.5 lb of solids per 100 lb of sludge), the daily volume wasted to the digester will be (834/0.015)/8.34 lb/gal = 6667 gallons. If the solids contain 70% VSS and 50 percent of the VSS are destroyed in the stabilization process, the solids destroyed per million gallons of sewage flow will be (834 lb/day) (0.7 VSS) (0.5 destroyed) = 292 lb/day. The solids remaining for disposal = 834 − 292 = 542 lb/day. The stabilized solids should consolidate to a 2 to

3% sludge. At 2.5% solids, the accumulation rate is = (542 lb/0.025)/8.34 lb/gal = 2599 gallons per day, for a reduction in volume of 39 percent during the stabilization process ([6667 gal – 2599 gal]/6667 = 0.61, or an accumulation rate of 61 percent). The supernatant return will be approximately 6667 gal – 2599 gal = 4068 gallons. The average sludge accumulation rate will be (6667 + 2599)/2 = 4068 gal/day. The air supply must provide adequate mixing of the digester contents and transfer the oxygen needed for aerobic stabilization.

Air requirements based on oxygen transfer are as follows: oxygen requirements = 2 pounds of oxygen per pound of VSS destroyed. Pounds of solids destroyed per day = 292 per million gallons of sewage treated.

Pounds of oxygen to be transferred per day = (2)(292) = 584.

At 10 percent transfer efficiency—5840 lb oxygen to be supplied.

Air is 20 percent oxygen; therefore, air requirements = 5840/0.20 = 29,200 lb/day.

One mole of air = 28.8 lb; air requirement is 29,200/28.8 = 1014 moles.

One lb mole = 359 ft^3, air volume = (1014)(359) = 364,026 ft^3/day = 253 SCFM/million gallons of sewage treated.

Air requirement based on mixing = 25 SCFM/1000 ft^3.

Digester volume = 20-day retention at 4068 gpd = 81,360 gal = 10,877 ft^3.

Air supply for mixing = (10,877/1000)(25) = 272 SCFM per million gallons of sewage treated.

The air requirement for mixing exceeds the oxygen transfer needs; therefore, the mixing requirements should be supplied. It should be noted that some diffuser designs are more than 10 percent efficient.

Stabilized sludge (biosolids) is a valuable resource that should be recycled back to the land where possible. Hauling and spreading of liquid sludge is the most convenient means of disposal where this option is available. Additional on-site storage volume may be needed at locations where there are periods when the spreading equipment cannot go onto the land. When sludge is applied to land, BOD, nitrogen, and phosphorus may be carried to surface streams by runoff during and following rainfall.

When it is not feasible to spread the liquid sludge, on-site air drying beds can be provided. Dried sludge is usually taken to the local landfill for disposal. Sludge from domestic sewage should not contain any constituents that would make the sludge unsuitable for land application. The design parameters for aerobic digestion at domestic sewage treatment plants are summarized in Table D.10. Design parameters will vary, depending on local winter temperatures. The engineer should be familiar with local requirements.

TABLE D.10 Design Parameter for Aerobic Digestion

Hydraulic retention period, days	15–20
Oxygen requirements, lb/lb VSS destroyed	2
Air requirements for mixing, SCFM/1000 ft^3	20–30

The engineer may design any size plant to be constructed of reinforced concrete in place. The size where the cast-in-place plant becomes economical or preferred depends on local conditions. Some owners prefer a constructed-in-place plant for a 30,000-gpd capacity, while others may prefer the lower first cost of a steel plant for even much larger treatment capacities. Either selection should give satisfactory service. However, the engineer is able to incorporate a more tailored design into the cast-in-place plant. The constructed-in-place concrete plant is not economical for installations having a capacity less than a few hundred thousand gallons per day.

The flow regime and the type of equipment included in the design are predetermined for the preengineered package plant. However, the engineer has a variety of configurations to choose from among the designs offered by the various suppliers. Generally, the package plant not only costs less than the tailored design but can be erected in less time. Additionally, steel tanks have a shorter life and require more maintenance than concrete tanks.

Several options for the design of a secondary treatment plant are presented herein. The batch reactor is one viable choice that has been well proven over years of use. Many other options are also available to the engineer, and more will certainly be developed. The National Small Flow Clearinghouse is a good source of current information (see Table D.5).

TERTIARY TREATMENT

Three common forms of wastewater treatment beyond the normal secondary level include filtration to reduce the BOD and suspended solids concentration, nitrification to reduce the nitrogenous oxygen demand, and nitrogen and/or phosphorus removal to reduce the level of these nutrients in the effluent. The batch reactor shown in Figure D.13 has been modified to accomplish both nitrogen and phosphoric removal. Other equipment suppliers also offer equipment suitable for use in treating small flows.

Filtration

The BOD of a secondary effluent is composed of both dissolved and suspended matter. Direct filtration reduces the suspended matter concentration, but has little effect on the dissolved BOD. The ratio of suspended solids to BOD for a good-quality secondary effluent is generally between 1.5 and 2.0. Most of the BOD is associated with the suspended solids. Normal granular media filtration reduces the suspended solids to a 4- to 6-mg/L range, and the BOD to between 5 and 8 mg/L. Chemical coagulation, flocculation, and sedimentation followed by filtration can reduce the suspended solids to about 2 mg/L and the BOD to a 3- to 5-mg/L range.

Well-designed and -operated secondary plants routinely produce effluents having a BOD and suspended solids less than 10 mg/L. However, small plants often do not receive the level of process operation and facility maintenance found at larger plants and excursions even higher than 30 mg/L may be common. Filtration should always be provided where permit effluent limits for BOD and suspended solids are less than 20 mg/L. This additional polishing operation should be evaluated for plants having effluent limits between 20 and 30 mg/L. Quality design and operation are required to meet an effluent limit of 20 mg/L on a continuing basis with secondary treatment alone. Chemical coagulation, flocculation, and sedimentation followed by filtration should be considered where the plant effluent BOD and suspended solids must be reduced to below a 7- to 10-mg/L range.

Down-flow granular media filtration of the type employed for potable water filtration is the most common technology used for wastewater polishing. This technology is well developed and gives reliable performance (the engineer should be sure to specify a proven technology). Down-flow granular media filters are of two broad types: deep bed and shallow bed. Both types are classified as rapid sand filters. Conventional deep bed filters contain 2 to 4 feet of filtering media supported by 1 to 1.5 feet of gravel, for a total bed depth of between 3 and 5 feet. Some package units employ an underdrain and backwash manifold that does not require the gravel support. The filtering medium may be silica sand or a combination of silica sand and anthracite coal (dual media), or a combination of sand, anthracite coal, and a denser material such as garnet (tri media).

Important characteristics of the filtering media include the porosity of the bed and the size of the voids between the media particles. Therefore, it is desirable to control the media particle size and the uniformity of the particles. The more uniform the particle size, the greater the bed porosity. Since it is not possible to achieve a condition where every particle is the same size, it would be desirable to have the larger particles at the top and the smaller particles at the bottom of the filter bed. However, sand filters are cleaned by backwashing, whereby water is distributed uniformly over the filter bottom at a sufficient flow rate to expand the bed and provide adequate agitation and scouring to remove the solids that were filtered out of the wastewater from the bed. When the bed is expanded, the filter medium is suspended by the upflowing water. This expansion and suspension result in a vertical stratification of particles based on particle size where all the particles have the same specific gravity. The particles are pulled down by gravity and are carried up by the rising water in relation to the surface area of the particle. The smaller particle has a greater surface area per unit volume. Thus, the backwashing of the filter stratifies the filter medium according to particle size, with the smaller at the top and the largest at the bottom. This is opposite what is desired because the larger voids are at the bottom of the bed and not at the top.

The dual media bed partly overcomes the problem of reverse stratification. By using two materials having different specific gravities and selecting the proper particle size, the medium having the smaller specific gravity stratifies at the top of the bed and the denser medium forms the bottom layer. However, each of the two media will still be stratified in reverse of what is desired. Dual media beds are composed of anthracite coal, which has a specific gravity of about 1.5, and silica sand, which has a specific gravity of 2.65. The anthracite can have a larger particle size, providing larger pores, which increases the bed capacity for removing solids. Tri media beds include a third medium such as garnet, which has a specific gravity of about 4.0. Characteristics of filter media are shown in Table D.11.

The dual media deep bed filter is commonly used for direct filtration of wastewater. The anthracite, having a larger particle size and, hence, larger voids, provides greater solids storage. The sand of smaller size forms a barrier that retards breakthrough of solids with the filter effluent. Filters are normally sized for a filtration rate of between 2 and 5 gpm/ft^2. A filter sized to operate at 2.5 gpm/ft^2 at average design flow should not exceed a 5.0 gpm/ft^2 rate during peak flow periods. A filter designed for an average filtering rate of 2.5 gpm/ft^2 requires a surface area of 28 ft^2 per 100,000 gpd capacity.

During the filtering operation, solids are removed from the flow and stored within the filter bed. These solids are washed deeper into the bed as filtering continues and eventually begin to appear in the filter effluent. Filters are backwashed to remove the collected solids when the head loss through the filter has reached a predetermined value (normally 8 feet for a conventional filter) or when there is a breakthrough of solids within the filter effluent. A run time between backwashing, when filtering a secondary effluent having suspended solids of 20 mg/L, is normally about one day. The most important design aspect of a filter is the backwashing operation. The backwash water must be applied uniformly over the entire filter bottom at a rate that produces the required bed expansion and scouring needed to remove the captured solids. Backwash rates are between 15 and 20 gpm/ft^2. If the backwash water is not applied uniformly over the filter bottom, the media will be deposited in the areas where the flow is the lowest and the

TABLE D.11 Filter Media Characteristics

Media	Specific Gravity	Effective Size	Uniformity Coefficient
Silica sand	2.65	0.50–0.55 mm	<1.65
Anthracite coal	1.50	1.0–1.2 mm	<1.65
Garnet	4.0	0.2–0.3 mm	<1.65

unexpanded areas will become compacted and ineffective for filtration. Inadequate application of backwash flow has been found to be a shortcoming with some package filters. If the bed expansion is insufficient to provide the necessary scour, the bed will not be cleaned and it will become necessary to backwash the filter again in a short time. The turbulence created by the high upflow rate of the backwash water scours the organic solids from the denser silica sand and carries the organics from the filter.

It is becoming more common to incorporate compressed air as a part of the backwash program. Air provides greater agitation and scouring, improving the removal of solids while reducing the water requirements and the backwash period. Air should always be considered as a part of the backwash procedure. Air is applied prior to start of the water flow and continued through part of the period of water backwashing. However, the application of air is discontinued before completion of the backwash cycle so the bed will properly stratify with the water flow. Air is used both as a surface wash to break up the media surface and as a part of the flow to the bottom of the media.

Figure D.20 shows a section view of a deep bed tri media filter of a type that is available as a package unit. Note that there is 5 feet of water over the media during the filtering period and 27 inches from the top of the bed to the top of the backwash trough. This 27 inches is needed to allow for the bed expansion during backwash so as to prevent media loss. Design provisions should be made for a minimum of 15 minutes of backwash. A 28 ft^2 filter washed at 20 gpm/ft^2 for 15 minutes requires 8400 gallons of backwash water (about 8 to 10 percent of the filtered water).

A conventional deep bed filtration operation has several requirements. First, it needs a source of backwash water, which must be previously filtered water. The chlorine contact tank is a good source of backwash water because the chlorine residual in the water retards the growth of slimes on the filter media. The design should also allow chlorine to be added ahead of the filter as needed for this purpose. If a chlorine contact tank supply is not available, a separate chamber must be provided to store backwash water. The volume stored should be sufficient to wash at least two filters.

A receiving tank for the backwash water is needed because the high backwash flow rate cannot be piped directly back to the secondary clarifier or other points in the treatment train. The backwash water should need clarification only before filtering and disinfection. It is not necessary to return this hydraulic load to the headworks of the plant.

The backwash flow can be piped to a holding tank, where the solids will settle to the bottom of the tank, permitting the decanting of most of the flow directly back to the filter influent, with the tank underflow containing the solids removed from the filter being returned to the secondary clarifier influent at a flow rate that does not overload the operation.

At plants that are subject to frequent periods of poor secondary effluents, a polymer can be added to the clarifier influent to improve solids capture in the clarifier. A high

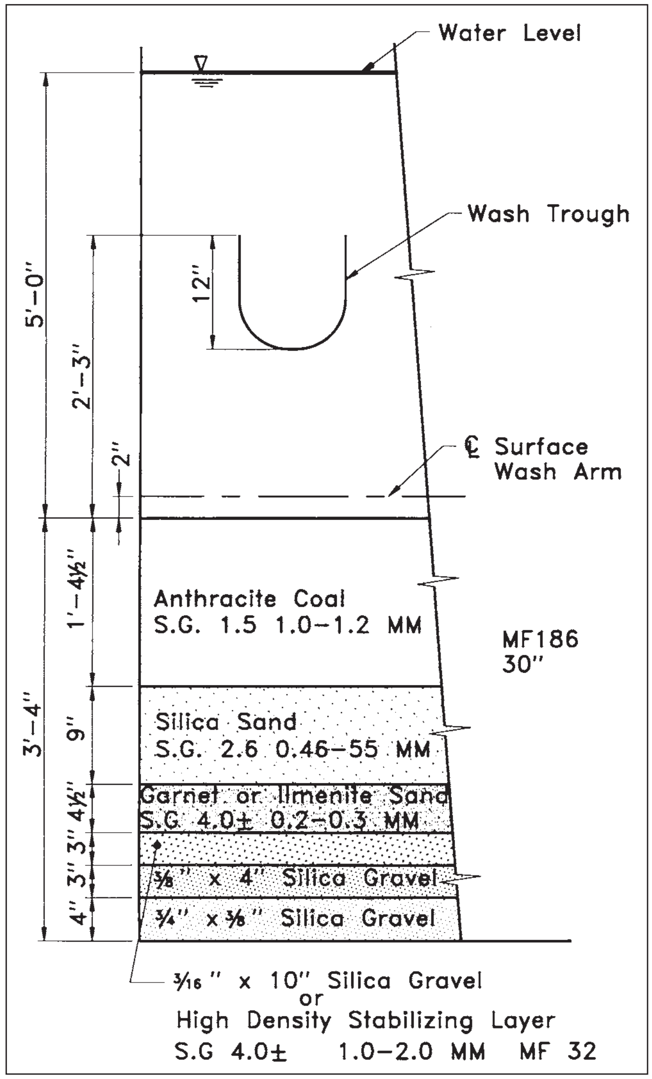

Figure D.20 Section view of a tri media filter. (Reproduced with permission from Wheelabrator Engineered Systems, Sturbridge, MA)

solids loading to the filter shortens filter run time between backwashing. This period can be shortened to the point at which sufficient water cannot be filtered to supply the backwash needs. The addition of a polymer to the clarifier influent will not increase sludge volume while materially improving solids capture. However, polymers should not be added on a continuous basis, but only on the infrequent occasion when needed because of a biological process upset. Polymer addition to the filter influent is not very effective because of the low solids concentration in the flow. The filtration process is improved by adding a flow equalization basin between the secondary clarifier and the filter. This additional basin should be sized to equalize the diurnal flow variation that constitutes a means of providing a constant filtration rate.

Another type of filter used in wastewater treatment is the *traveling bridge filter.* This is a shallow bed filter, having a media depth of 12 to 15 inches and generally a single filter medium. The filter bed is divided into cells. A schematic view of a traveling bridge filter is shown in Figure D.21. The traveling bridge carries a backwash pump and hood along the filter. As the hood passes over a cell formed between two adjacent partition plates, the pump on the bridge draws water from a plenum underdrain up through the sand, where it is discharged into a trough located along a wall on one side of the filter. The pump and hood are designed to provide the proper upflow rate uniformly over the area being backwashed. Since only a single cell is being backwashed at a time, the backwash flow rate is relatively low and the flow can usually be returned directly to the influent of the secondary clarifier. Since the water for backwashing comes from the underflow plenum, the cells not being backwashed supply the backwash water for the cell being cleaned. The operation requirements of the traveling bridge filter make it an option that should be considered for a small plant. Filtration rates are similar to those for the deep bed filter. Bed load capacity is less than that expected from the deep bed filter because of the shallow depth and the use of a single medium. Therefore, the frequency of cell backwashing is shortened.

There are several purveyors of well-developed package filters, both dual and tri media deep beds and the traveling bridge filter. Engineers are well advised to consider a package unit design for small plants. The package units are generally piped and valved to provide automatic operation. Design and on-site construction of filter units is not economical for small plants. Catalog data for the selected unit should be used for incorporating the unit(s) into the overall design. Filters should be housed in a building at locations where freezing weather occurs in the winter months.

A pilot study would normally be conducted at larger plants to obtain design data, but studies of this type are not feasible for small plants. The engineer should be conservative in a filter design for a small plant. When the effluent limits are less than about 8 mg/L for BOD and suspended solids, chemical coagulation, flocculation, and sedimentation should precede filtration. The process chain is the same as is used for water treatment and package units, providing the entire operation from chemical addition through filtration in a single unit are available, and should be used at small plants. A backwash water supply and receiving tank is

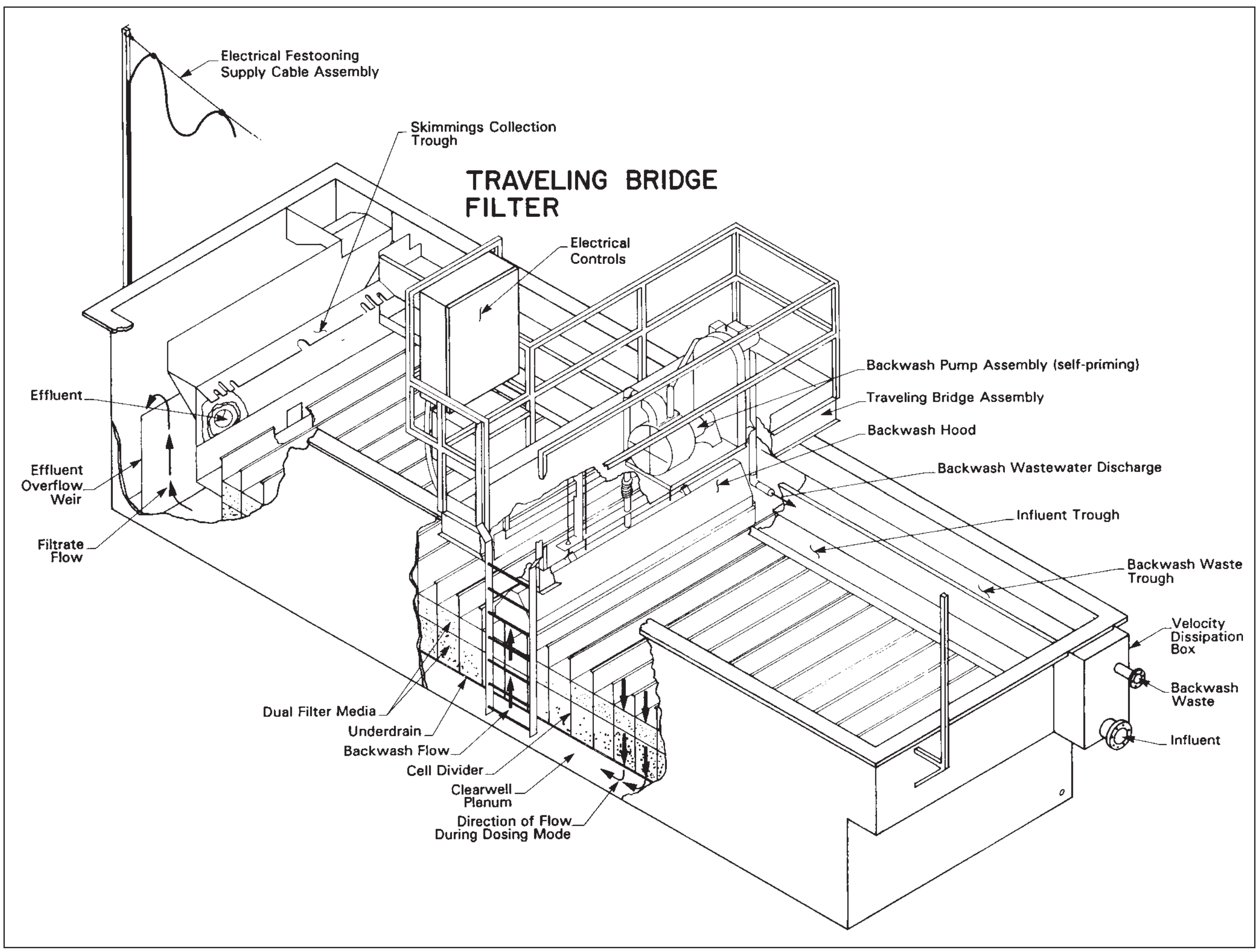

FIGURE D.21 Sectional view of a traveling bridge filter. (Reprinted with permission from Davis, Water & Waste Industries, Inc., Thomasville, GA) needed to complete the operation. In addition, provisions must be included in the design for handling the sludge generated.

Filtration is not a means of correcting for poor operation of secondary treatment. If poor-quality secondary effluent is applied to a filter, the filtering system will fail.

Nitrogen and Phosphorus Control

As noted earlier in this chapter, nitrogen and phosphorus are generally the growth-limiting nutrients in aquatic environments. Phosphorus is most often the growth-limiting element in fresh water and nitrogen in marine environments. Secondary effluents from plants treating domestic sewage normally contain 20 to 40 mg/L of total nitrogen and 8 to 15 mg/L of total phosphorus. Normally, the total nitrogen is primarily in the ammonia or nitrate form and the phosphorus is present as phosphate. These forms are readily available to aquatic flora and can contribute to the eutrophication of lakes, ponds, and estuaries.

Nitrogen Oxidation and Removal. Ammonia is an intermediate compound, which results from the decomposition of protein. Mammals, including humans, eliminate most excess nitrogen from the body via the urinary pathway in the form of urea. Urea is rapidly hydrolyzed after leaving the body, releasing ammonia. Ammonia is common to all domestic wastewater. Ammonia is the reduced form of inorganic nitrogen in surface waters. Ammonia should be oxidized to the nitrate form because in its reduced form it places an oxygen demand on the receiving water. Additionally, ammonia is toxic to many forms of aquatic life, even in low concentrations. The activated sludge biomass generally contains both heterotrophic and autotrophic bacteria. The nitrifying autotrophs absorb ammonia and oxidize it to nitrates according to the following sequential reactions.

$$\text{Ammonia} + 1.5\ \text{Oxygen} \rightarrow \text{Nitrite, Nitrite} + 0.5\ \text{Oxygen} \rightarrow \text{Nitrate}\ NH_4 + 1.5\ O_2 \xrightarrow[\textit{Nitrosomonas sp.}]{} NO_2 + 0.5\ O_2 \xrightarrow[\textit{Nitrobacter sp.}]{} NO_3 \qquad \text{(D.7)}$$

Two species of autotrophic bacteria are needed to complete the oxidation process. Both species are more sensitive to temperature and pH than the heterotrophic species. Nitrobacter is more sensitive to low temperature than Nitrosomonas. It is not uncommon during winter months to find relatively high concentrations of nitrites in a secondary effluent. Nitrites are subject to chemical oxidation and express a high chlorine demand when present in the effluent. When ammonia is expressed as nitrogen, 4.6 mg/L of oxygen are required to oxidize 1 mg/L of ammonia (64/14). Thus, an ammonia concentration of 25 mg/L requires 115 mg/L of oxygen to complete the oxidation. The engineer must provide sufficient oxygen to meet the nitrogenous demand.

Heterotrophic bacteria, which use carbon-based organic material for food and growth, have a high cell yield and undergo rapid growth when fed. In contrast, the autotrophic bacteria use inorganic substances for growth and therefore have a much slower growth rate and cell yield. In conventional activated sludge, the autotrophs are maintained by carrying a long sludge age. Even under these conditions, the autotrophs may be overgrown and unable to compete in the environment. The autotrophs prefer surfaces for growth, and nitrification can be improved by providing surfaces for maintaining the population. The surfaces should be located after the uptake phase for the heterotrophs has occurred. Plastic plates may be placed vertically near the effluent end of the aeration tank to provide growth surface for the nitrifiers. Air must be supplied to the area for mixing and to provide an oxygen supply. It may be impossible to achieve nitrification in small plants during winter months if the liquid temperature drops below 15°C. It is not uncommon for the NPDES permit to not require nitrification during winter months for plants located in northern latitudes.

The most suitable means of nitrogen removal is the biological process of *denitrification.* In an anoxic environment (absence of free oxygen, but not anaerobic where reduction reactions occur) the facultative biomass uses oxygen from compounds such as nitrates as an electron acceptor. The nitrates are not reduced back to ammonia but to nitrogen gas, as shown by the following generalized reaction.

$$NO_3 + \text{Organic Carbon} \xrightarrow[\text{Anoxic Conditions}]{\text{Facultative Heterotrophs}} N_2\ (\text{gas}) + CO_2 \qquad \text{(D.8)}$$

There are several biological processes for accomplishing the preceding reaction as a part of an activated sludge process. The batch reactor is one example. Older designs use a separate operation for denitrification. An energy source is required for the bacteria. The organic carbon can be supplied by raw sewage. The contact vessel is mechanically stirred to keep the biomass in suspension and in contact with the food source. The mixing releases the nitrogen gas to the atmosphere. When a separate operation is selected, the additional piping and tankage requirements, together with the additional operational requirements, may represent a major burden for small treatment plants.

Phosphorus Removal. Phosphorus can readily be removed from wastewater by chemical precipitation, using alum, sodium aluminate, lime, or iron salts. Alum is the most common physical-chemical process employed for phosphorus removal in wastewater treatment. When aluminum is used, phosphates are precipitated as aluminum phosphate according to the following reaction:

$$Al_2(SO_4)_3^{-14}\ H_2O + 2\ PO_4^{-3} \rightarrow 2\ Al\ PO_4 + 3\ SO_4^{-3} + 14\ H_2O \qquad \text{(D.9)}$$

It is generally necessary to add 15 to 20 pounds of alum per pound of phosphorus present. Actual chemical requirements should be determined by laboratory test on the wastewater to be treated. Some package plants incorporate biological phosphorus removal capability (see previous discussion of the batch reactor). At plants where an anoxic condition is created for nitrate reduction, the phosphorus is precipitated as elemental phosphorus. Thus, the anoxic process is effective in removing both nitrogen and phosphorus. Several equipment suppliers offer package units that can be operated to remove both phosphorus and nitrogen as a part of secondary treatment.

At plants employing primary treatment, alum or iron salts may be added ahead of the primary clarifier to remove phosphorus as a part of the primary sludge volume.

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APPENDIX E

WATER SUPPLY AND TREATMENT

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Updated/Revised: Charlie C. Crowder, Jr.

INTRODUCTION: WATER SUPPLY PLANNING AND ENGINEERING

Water supply and treatment requirements are significant factors during land use planning and remain a top consideration in long-term strategies to sustain capital investments, infrastructure, and land development projects. The land development industry will continue to warrant the services of water supply and treatment consultants—professional engineers, planners, and scientists—to help clients envision, design, construct, and manage the water supply aspects of their developments.

As indicated in Chapter 5, early consideration of potable water factors is necessary. From identifying the available natural and man-made resources to gauging available system capacity, treatment, and permit requirements, front end investigation is invaluable to ensure the long-term serviceability of a given project. A thorough understanding of the project's water-related issues by both the client and the consultant will preclude surprises, facilitate smooth scheduling of design and construction activities, clarify development and subsequent maintenance and operation costs, and ensure appropriate coordination with other site features. Especially when on-site water supply and treatment is determined to be necessary, water availability coordination is a project management priority.

Heightened public health, environmental safety, and sustainability concerns coupled with increased consumer expectations have resulted in additional, more stringent water treatment regulations that greatly impact land development considerations. Understandably, developments that are able to tap an existing municipal system will be less directly concerned with the functional mechanics and regulations associated with off-site upstream treatment and can focus on sustainability efforts including both water system capacity improvements and conservation or demand reduction strategies. Those developments subject to on-site supply and treatment must be innately aware of regulatory conditions related to treatment requirements and service capacity as well as sustainability issues. Moreover, in many areas of the United States and the world, stakeholders readily express that water is their number one concern as it relates to growth and development. Thus, incorporation of and sensitivity to sustainability efforts can go a long way toward assuaging neighbors, public officials, and consumers as they relate to potential projects.

The demand for future water supply services is evident; the U.S. Environmental Protection Agency (EPA) reports ". . . thirty-six states are anticipating local, regional, or statewide water shortages by 2013; even under non-drought conditions." This underscores the need for development plans that consider short-term and long-term water supply strategies.

Water quality and quantity issues are largely site-specific in nature: what works best and is permitted at one location is often not available, feasible, or permitted, technically or environmentally, at another site. For instance, in some parts of the United States, the water treatment process *train* (*train* is the term used in the water industry to describe the treatment process sequence) is permitted to direct filter without clarification (coagulation, flocculation, and sedimentation) because of the characteristics and turbidity of the available surface water. A more apparent example of the site specificity of water supply occurs when ground water is available for a development project; often ground water sources require limited treatment processes and less monitoring.

The role of the consulting engineer in addressing and solving water supply and treatment issues will likely increase in complexity and value regardless of how regulatory approvals and permits for potable water supply projects are obtained, whether by one or more of the following solutions: connecting to established water utilities through pipeline extensions, additions, and alterations; drawing from approved household or community well systems; or producing from an on-site water treatment package plant that has been selected (or designed) and approved to fulfill the regulatory requirements of the particular project. Timely, proficient, and seasoned project management will be valued in precluding water facilities from becoming the critical path of the land development project schedule. Extensive coordination with legal, financial, architectural, engineering, and environmental consultants along with construction personnel, equipment and material suppliers, government agencies, and project neighbors and stakeholders will be necessary for successful implementation of required water supply and treatment operational infrastructure. Knowledge of water regulations and standards combined with effective project leadership and leveraging of engineering technology can result in optimal usage and expansion of the water supply resources vital to fostering the health, welfare, and longevity of the community.

WATER SYSTEM STATISTICS AND TERMINOLOGY

Briefly stated, a land development site can be supplied drinking water from a public or private water utility or, if an established water system is not available, from a supply system developed for the particular site. The water source can be ground water (wells, springs), surface water (lake, river, or stream), or ground water under the influence of surface water. For the purposes of treatment, the regulatory agencies consider ground water under the influence of surface water as surface water. In the United States, drinking water regulations for all source waters are administered by the EPA primarily through the Safe Drinking Water Act (SDWA). It is applicable to all public water systems (PWSs) with at least 15 service connections or at least 25 people per day for 60 days of the year.

In 2005, there were approximately 158,000 PWSs in the United States (see Figure E.1) of which nearly 53,000 supply water to the same population—over 282 million people—year-round. These systems are known as *community water systems* (CWSs). Most people in the United States get their drinking water from the larger CWSs (those serving a population of 3300 or more); in fact, 91 percent of the population is served by only 17 percent of the systems. While the remaining 83 percent of the water supply systems (small systems serving less than 3300 persons) accommodate only a small population, they are subject to virtually the same rules and regulations as larger systems. The classification of water systems is particularly noteworthy as development continues to expand outside of established and planned public infrastructure boundaries. Thus, while it may seem intuitive to provide a small on-site system such as a community well or package plant to accommodate a proposed development, the SDWA (detailed next) has made it such that even small systems, previously exempt, quickly approach a size that triggers stringent regulations.

Drinking Water Regulations and the Safe Drinking Water Act (SDWA)

The SDWA was passed in 1974, then reauthorized and amended by Congress in 1986 and 1996. Initially, the act protected drinking water supplies by requiring the EPA to regulate contaminants that pose health risks and are known or likely to occur in drinking water. As a result of the legislation, the EPA established *maximum contaminant levels* (MCLs). Initially, the focus of the act was on treatment as the means of providing safe drinking water at the tap. The 1986 amendments strengthened the initial regulatory approach by requiring additional MCLs, specifying certain treatment process applications such as disinfection and filtration based on source water characteristics, and implementing wellhead protection and sole-source aquifer programs. The 1996 amendment further expanded the scope of the SDWA by recognizing source water protection, operator training, funding for water system improvements, and public information as important components of safe drinking water (see Table E.1), thus ensuring the quality of drinking water by protecting it from source to tap.

The primary role of the federal government under the SDWA is to develop national drinking water regulations to protect public health. The states have the responsibility of implementing and enforcing the regulations for public water systems within their jurisdictions. State agencies (all states except Wyoming) and the EPA entered into primacy agreements to establish enforcement authority. State and local regulatory agencies (typically a division of the health department) occasionally have more stringent water quality standards than those of the SDWA. Consequently, the private consultant must develop water supply designs that adhere to both the SDWA and the state and local jurisdiction.

SDWA Rules

The SDWA and its amendments have enabled the EPA to produce updated standards and influence the implementation of new technologies. Many of the regulatory requirements are presented as rules addressing specific aspects of water supply and treatment. Summaries of some salient rules stemming from the SDWA that generally bear weight in terms of evaluating new water treatment facilities for development projects include the following:

- *Total Coliform Rule (TCR):* The TCR sets monitoring requirements in water systems for coliforms, indicators of potential fecal contamination.
- *Surface Water Treatment Rule (SWTR):* First published in 1989, the SWTR specifies that water from surface sources receive certain site-specific filtration and related treatment. Additionally, it establishes disinfectant concen-

Public Water System Inventory data

Active, current systems, from Safe Drinking Water Information System/Federal version (SDWIS/FED) 05Q4 frozen inventory table

System size

by population served

		Very Small 500 or less	Small 501-3,300	Medium 3,301-10,000	Large 10,001-100,000	Very Large >100,000	Total
CWS	# systems	29,666	14,389	4,748	3,648	386	52,837
	Pop. served	4,925,748	20,851,292	27,514,714	102,747,558	126,304,807	282,344,119
	% of systems	56%	27%	9%	7%	1%	100%
	% of pop	2%	7%	10%	36%	45%	100%
NTNCWS	# systems	16,348	2,707	102	17		19,174
	Pop. served	2,282,628	2,710,912	557,742	504,915		6,056,197
	% of systems	85%	14%	1%	0%	0%	100%
	% of pop	38%	45%	9%	8%	0%	100%
TNCWS	# systems	83,351	2,721	111	23	4	86,210
	Pop. served	7,298,704	2,667,051	598,506	604,213	2,994,000	14,162,474
	% of systems	97%	3%	0%	0%	0%	100%
	% of pop	52%	19%	4%	4%	21%	100%
	Total # syster	129,365	19,817	4,961	3,688	390	158,221

CWS = Community Water System: A public water system that supplies water to the same population year-round.

NTNCWS = Non-Transient Non-Community Water System: A public water system that regularly supplies water to at least 25 of the same people at least six months per year, but not year-round. Some examples are schools, factories, office buildings, and hospitals which have their own water systems.

TNCWS = Transient Non-Community Water System: A public water system that provides water in a place such as a gas station or campground where people do not remain for long periods of time.

Water source

Type		Ground Water	Surface Water	Totals
CWS	# systems	40,018	11,737	51,755
	Pop. served	89,539,197	191,130,147	280,669,344
	% of systems	77%	23%	100%
	% of pop	32%	68%	100%
NTNCWS	# systems	18,438	607	19,045
	Pop. served	5,410,376	611,002	6,021,378
	% of systems	97%	3%	100%
	% of pop	90%	10%	100%
TNCWS	# systems	83,930	1,852	85,782
	Pop. served	11,305,555	801,399	12,106,954
	% of systems	98%	2%	100%
	% of pop	93%	7%	100%
	Total # syster	142,386	14,196	156,582

Ground water systems = ground water (GW), purchased ground water (GWP)
Surface water systems = surface water (SW), purchased surface water (SWP),
ground water under the direct influence of surface water (GU),
purchased ground water under the direct influence of surface water (GUP).

SDWIS/FED 05Q4 tables were "frozen" in early January 2006

FIGURE E.1 FY2005 drinking water statistics. (U.S. EPA, 2006)

tration time (CT) calculation requirements to combat *Giardia, Cryptosporidium,* and other pathogens through sufficient contact time. As a result of regulatory enhancements and the EPA promulgation in 2006 of the Long Term 2 Enhanced Surface Water Treatment Rule, often referred to as LT2ESWTR, water systems are "to monitor their source water, calculate an average *Cryptosporidium* concentration, and use the results to determine if their source water is vulnerable to contamination and may require additional treatment. Filtered systems serving less than 10,000 may be eligible to conduct *E. coli* source water monitoring in lieu of *Cryptosporidium* monitoring."

TABLE E.1 1996 SDWA Amendment Highlights

CONSUMER CONFIDENCE REPORTS
All community water systems must prepare and distribute annual reports about the water they provide, including information on detection contaminants, possible health effects, and the water's source.
COST-BENEFIT ANALYSIS
U.S. EPA must conduct a thorough cost-benefit analysis for every new standard to determine whether the benefits of a drinking water standard justify the costs.
DRINKING WATER STATE REVOLVING FUND
States can use this fund to help water systems make infrastructure or management improvements or to help systems assess and protect their source water.
MICROBIAL CONTAMINANTS AND DISINFECTION BY-PRODUCTS
U.S. EPA is required to strengthen protection for microbial contaminants, including Cryptosporidium, while strengthening control over the by-products of chemical disinfection. The Stage 1 Disinfection and Disinfection By-products Rule and the Interim Enhanced Surface Water Treatment Rule together address these risks.
OPERATOR CERTIFICATION
Water system operators must be certified to ensure that systems are operated safely. U.S. EPA issued guidelines in February 1999 specifying minimum standards for the certification and recertification of the operators of community and nontransient, noncommunity water systems. These guidelines apply to state operator certification programs. All states are currently implementing EPA-approved operator certification.
PUBLIC INFORMATION AND CONSULTATION
SDWA emphasizes that consumers have a right to know what is in their drinking water, where it comes from, how it is treated, and how to help protect it. U.S. EPA distributes public information materials (through its Safe Drinking Water Hotline, Safewater website, and Water Resource Center) and holds public meetings, working with states, tribes, water systems, and environmental and civic groups, to encourage public involvement.
SMALL WATER SYSTEMS
Small water systems are given special consideration and resources under SDWA, to make sure they have the managerial, financial, and technical ability to comply with drinking water standards.
SOURCE WATER ASSESSMENT PROGRAMS
Every state must conduct an assessment of its sources of drinking water (rivers, lakes, reservoirs, springs, and ground water wells) to identify significant potential sources of contamination and to determine how susceptible the sources are to these threats.

- *Stage 1 Disinfectants/Disinfection Byproducts Rule (D/DBPR):* This rule is designed to protect the public against the long-term, or chronic, effects of exposure to disinfection byproducts (DBPs), especially those formed using chlorine. This rule decreased the allowable limits for total trihalomethanes (THMs) and set limits for other DBPs. The Stage 2 Disinfectants and Disinfection Byproducts Rule (Stage 2 D/DBPR), promulgated by the EPA in 2006, builds on Stage 1 and focuses on "monitoring for and reducing concentrations of disinfection byproducts," trihalomethanes and haloacetic acid (THMs and HAA5). The LT2ESWTR and Stage 2 DBPR are thus regulatory complements in addressing salient water treatment issues. Water systems serving less than 10,000 do not need to complete an initial distribution system evaluation but must conduct Stage 2 D/DBPR compliance monitoring.

- *Filter Backwash Recycling Rule:* This rule requires filter backwash streams, when recycled, to be returned to a point in the treatment plant process train where they go through all the steps of the approved treatment system.

- *Lead and Copper Rule:* This rule is meant to protect consumers from exposure to corrosion in the distribution system such as lead or copper leachate from plumbing fixtures.

- *Arsenic Rule:* This rule lowered the allowable limit for arsenic in CWSs. The original MCL (established 1975) for this well-known poison was 50 mg/L; the revised MCL is 10 mg/L, which affects many ground water and some surface water systems.

- *Radionuclides Rule:* The Radionuclides Rule requires all water systems to have completed initial monitoring for radium and uranium by December 31, 2007. Subsequently, water systems need to obtain guidance and direction from their respective state primacy agencies to ascertain future monitoring and actions required to reduce exposure to radionuclides. There is a separate rule proposed to address radon in water. Radon's principal danger to consumers is from inhalation of the gas when it becomes airborne, for example, in a bathroom shower.

- *Ground water Rule:* This rule was proposed in 2000 and the final rule published in 2006; the rule seeks to reduce the risk of exposure to fecal contamination possibly present in ground water sources. An approach called *risk-targeting* requires an initial sanitary survey and specifies source water monitoring to test for the presence of *E. coli,* enterococci, or coliphage. Corrective actions are required for a significant deficiency or source water fecal contamination. Options include provision of an alternative source of water, elimination of the contamination source; treatment (99.99 percent inactivation), and correction of all significant deficiencies.

The Internet greatly facilitates communication of water industry regulatory and technical information among the EPA, the water utilities the EPA regulates, and state primacy agencies and consultants. The EPA website (http://www.epa.gov/safewater/sdwa/index.html) is comprehensive and serves as a vital reference and source of current regulatory information. It provides guidance on procedures, protocols, testing requirements, and links to approved technical information, other related potable water safeguards, and sanitation considerations. Likewise, state primacy agencies have their respective websites and links to help disseminate local requirements, permit information, and processing protocols. Often included on state sites are lists of approved materials and equipment and links to water industry literature, guidance documents, and reference materials. Reference materials typically include approved standards and codes, such as those of the American Water Works Association (AWWA) and other approved resources from organizations like the National Drinking Water Clearinghouse at West Virginia University and the National Sanitation Foundation International (NSF) among others.

OVERVIEW OF ON-SITE WATER TREATMENT SYSTEMS

Chapter 25 largely describes the planning and design of water distribution systems. This chapter addresses instances where there is no established potable water system to serve a proposed development. The consultant must then identify options for sufficient water supply, implement required treatment facilities, and engineer the distribution system. The principles of water supply and treatment, as discussed in this chapter, generally apply to large and small systems. However, this discussion leans toward small systems since the majority of water systems, nearly 83 percent, are considered small systems.

In evaluating available water supply sources, the primary objective is to obtain a source (or sources) that have acceptable, sustainable quantity and the best available quality that is suitably and economically located near the anticipated point of use. As outlined in Figure E.1, most small water supply systems in the United States use ground water as their source. For small systems and low flows, ground water sources are typically less difficult and less costly to develop and operate compared to surface water sources. However, discussion of surface water sources is included in this chapter for those instances where suitable ground water is not available.

GROUND WATER

Within a development, it is not uncommon for the water supply of an individual homeowner to come from a private well, nor is it uncommon for a single private or public well to serve many houses. Using a ground water supply presents challenges different from a conventional public system for quantity and quality—whether sufficient water is available and whether it is of potable standards. Additionally, once the ground water source is identified as usable, measures must be exercised to keep the source from pollution.

It should be noted that private wells (or systems with less than 15 connections or serving less than 25 people) are not regulated under the SDWA. One out of every seven people in the United States (about 15 percent) has a private drinking water supply, such as a well, cistern, or spring.

While ground water is available nearly everywhere, the difficulty is recovering ground water; due to the depth of the water table, it may prove costly. In a development where the same aquifer will potentially be used by numerous households, assurances must exist that there is sufficient water yield for everyone and that natural replenishment of the aquifer is compatible with the amount used.

Ground water exists in two major subsurface zones, the boundary of which is the water table. Above the water table, the pore spaces of the aeration (or unsaturated) zone are filled with air and water. The high fluctuation in moisture content in this zone is affected by such things as temperature, humidity, precipitation, vegetation, and the intrinsic properties of the porous media. Below the aeration zone (and the water table) lies the saturation zone. Here, the pore spaces contain only water, which is available for consumptive use. Although the shape of the water table generally follows the ground surface, its depth fluctuates seasonally and is affected in part by climate and geologic conditions.

An aquifer is a water-bearing geologic formation capable of storing, transmitting, and providing freshwater in usable quantities. In order to do this the geologic formation must have interconnecting pores and open spaces of sufficient size to allow the movement of water. The open space within the aquifer, occupied by ground water, may only consist of small interstices between loose grains or may include large geologic cavities. As shown in Figure E.2, there are two basic types of aquifers: an unconfined aquifer and a confined aquifer.

The unconfined aquifer has the water table as its upper boundary and an impermeable layer as the lower boundary. Water pumped from a well in an unconfined aquifer lowers the water table near the well. Gravity then causes ground water to flow toward the well. Replenishment results from the surface waters in the overlying area that infiltrate deep enough into the unsaturated zone and eventually end up in the aquifer through lateral movement.

Ground water in a confined aquifer is bounded between two layers of impermeable material. Because of such confinement, the overburden and atmospheric pressure create a pressure head that causes water in a well, placed in that aquifer, to rise above its upper boundary. Occasionally, when a well penetrates the confined aquifer, the pressure head is enough to cause the water to rise above the ground surface. This is known as an *artesian well.* It is important to note that the replenishment (recharge) area for a confined aquifer is not the overlying surface, due to the impermeable upper layer. The rate of ground water movement is highly variable and can range from several feet per year to several feet per day, depending on the soil and rock characteristics. This movement results from the combined effects of gravitational forces and the hydraulic gradient. The hydraulic gradient is the head loss per unit length of flow path. Darcy's equation states that the velocity of water through a porous medium is proportional to the hydraulic gradient, or in equation form:

$$v = Ki \tag{E.1}$$

where v, the discharge velocity for laminar flow conditions, is the quantity of water flowing in unit time through a unit gross cross-sectional area of soil at right angles to the direction of flow (fps); K is a proportionality constant (also of fps) referred to as the hydraulic conductivity; and I is the hydraulic gradient in feet per foot ($i = h/L$). Combining Darcy's equation with the continuity equation gives the flow rate through a porous medium:

$$Q = KA\left(\frac{h}{L}\right) \tag{E.2}$$

where Q = flow (ft^3/sec). Figure E.3 identifies the terms used in Equation E.2 and shows the relationship of hydraulic gradient to hydraulic head using the concepts presented in Equation 25.15. Note that the direction of flow is controlled by the hydraulic gradient (i.e., right to left) and not by what gravity might indicate (left to right). The underlying assumptions for Darcy's law are that inertial forces are negligible and

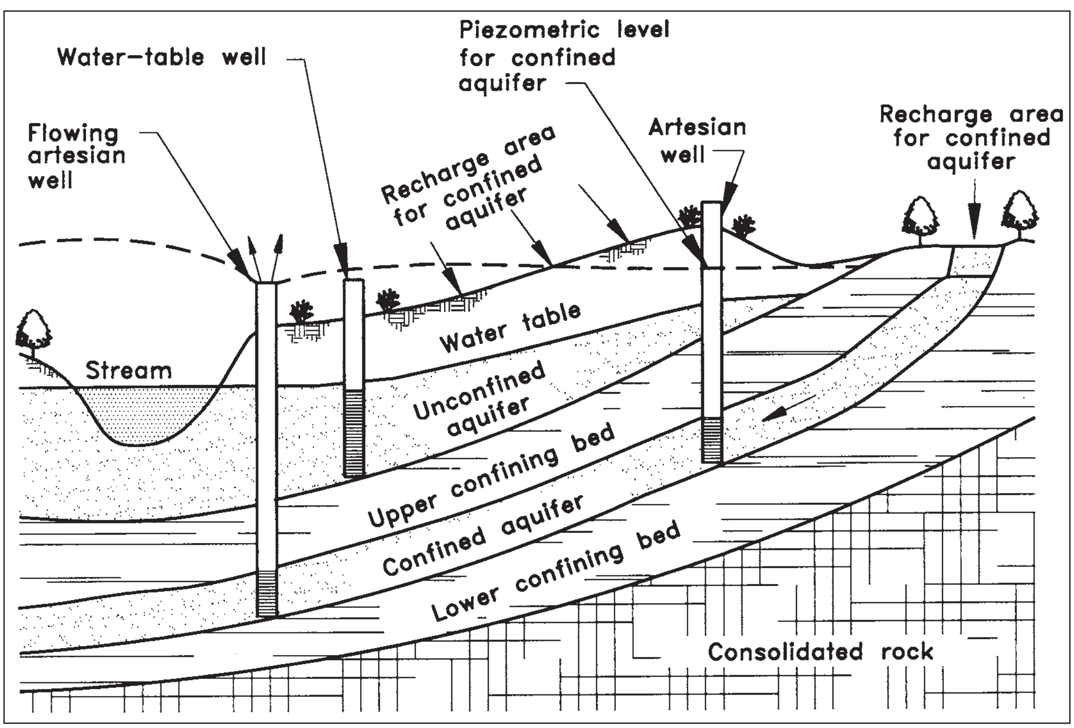


FIGURE E.2 Types of aquifers.

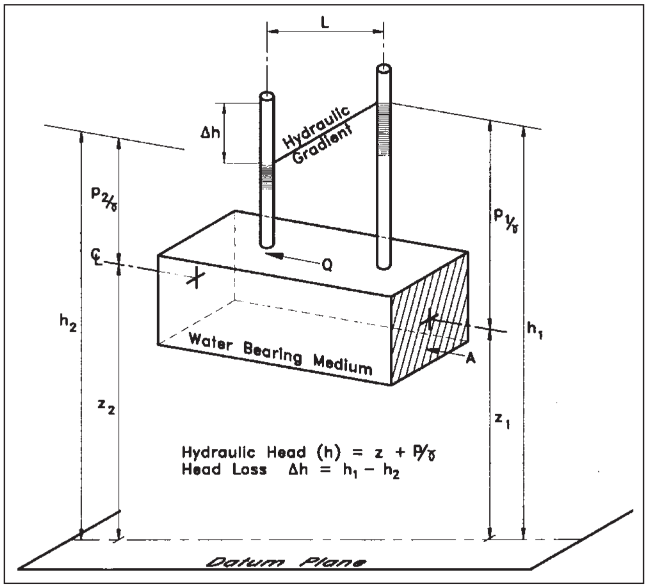


FIGURE E.3 Darcy's law.

flow is laminar, steady, and nearly uniform. The first two assumptions can be combined by the further restriction that the Reynolds number must be between 1 and 10.

Porosity and hydraulic conductivity affect ground water movement rates. Porosity, the total volume of pore space within a given volume, is a measure of the medium's ability to hold a volume of water. Hydraulic conductivity is the relative ease with which water moves through the pores under a hydraulic gradient. The hydraulic conductivity K depends on the physical properties of the porous media and the fluid. In terms of fluid and media characteristics, K is expressed as

$$K = \frac{Cd\rho g}{\mu} \tag{E.3}$$

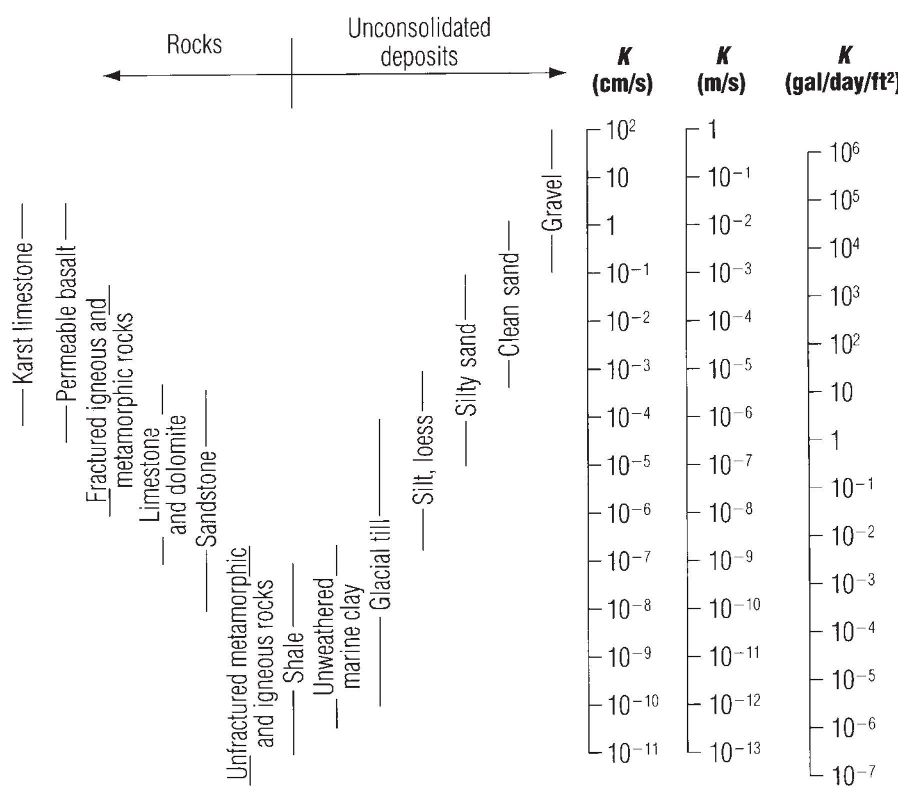
where d = mean grain diameter, ρ = fluid density, μ = absolute viscosity of the fluid, g = gravitational acceleration, and C is a dimensionless constant, which is a function of grain size, sphericity, roundness, and the nature of the grain.[1]

Tables E.2 and E.3 identify values of hydraulic conductivity and porosity, respectively, for various soil types. Conceivably, a soil can have a high porosity and yet have a low permeability rate.

Although the total volume of the ground water is equivalent to the volume of the voids in the saturated zone, the actual amount of ground water available for use (i.e., specific yield) is less due to unavailable water that is semipermanently attached through surface retention to the surface of the soil and rock aggregates. Specific yield is a function of particle size and shape, distribution of pore space, and degree of compaction of soil.

[1]Hydraulic conductivity equation from Ponce, p. 340. He footnotes it from *Journal of Geology,* vol. 48, pp. 785–944; *The Theory of Ground water Motion* by M.K. Hubbert.

TABLE E.2 Range of Values of Hydraulic Conductivity



(Courtesy of Freeze/Cherry, *Ground water* ©. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

TABLE E.3 Range in Porosity for Selected Earth Materials

MATERIAL	POROSITY (%)
Gravel, clean-uniform	20–50
Sand, clean-uniform	20–40
Sand and gravel mixed	10–30
Salt and clay	
As deposited	40–70
Compacted	0–40
Shale	1–20
Sandstone	5–30
Limestone	1–20

Courtesy of Freeze/Cherry, *Ground water,* © 1979, p. 37. Reprinted by permission of Prentice Hall, Englewood Cliffs, New Jersey.
Courtesy of Freeze/Cherry, *Ground water,* ©. Reprinted by permission of Pearson Education, Inc., Upper Saddle River, New Jersey.

Transmissivity and Cone of Depression

Many problems with developments using wells is the underestimation of available ground water for the proposed number of dwelling units. If more wells are attached to the same aquifer, and if the increased pumping is beyond the natural recharge rate of the aquifer, drawdown of the water table will result. Furthermore, the drawdown affects the shape of the water table around the well.

Transmissivity is a measure of the entire aquifer's ability to transmit water. Transmissivity is the flow rate (in gpd) moving through the entire saturated thickness of an aquifer having a unit width under a unit hydraulic gradient. Mathematically, transmissivity is expressed as

$$T = Kb \quad \text{for confined aquifers} \tag{E.4}$$

$$T = K\overline{D} \quad \text{for unconfined aquifers}$$

where T = transmissivity, K = hydraulic conductivity, b = saturated thickness in the confined aquifer, and D = average saturated thickness of the unconfined aquifer.

The shape of the water table surface changes as water is pumped from the unconfined aquifer. In fact, the water table surface converges at the well intake and tends to resume the natural water table elevation as the distance away from the well increases. The resulting shape, an inverted cone, is referred to as the *cone of depression* (see Figure E.4). The difference between the natural water table elevation and the depressed water surface is the *drawdown*. The shape of the cone depends on how far the well penetrates the aquifer, the length of the screen intake, the pumping rate, transmissivity of the aquifer, and other factors. All else being equal, the lower the transmissivity, the more pronounced the cone of depression. Low transmissivity causes a deep cone with a small base and steep sides, whereas a high transmissivity in the aquifer creates a shallow cone with a large base and flat-sided slopes for the same pumping rate.

The well discharge rate is affected by both the radius of the cone and the drawdown height at the well casing. The well discharge equations for equilibrium conditions are based on the following assumptions:

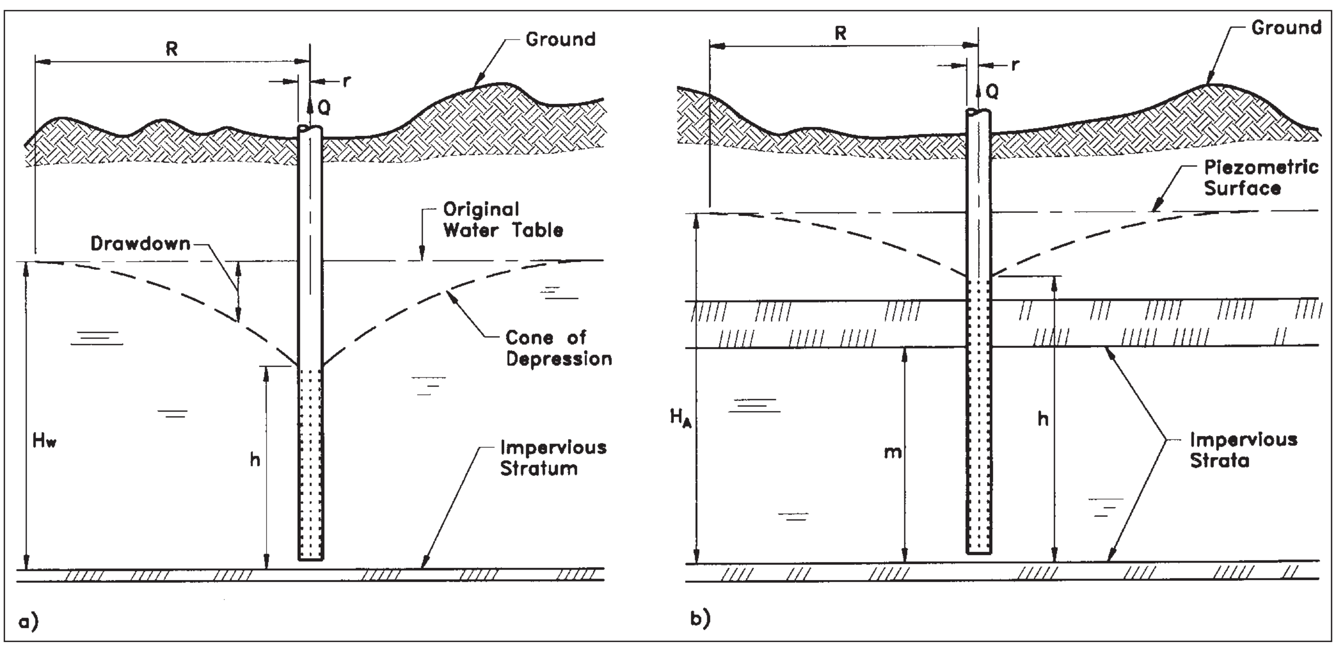


FIGURE E.4 Radial flow to an aquifer: (*a*) unconfined flow; (*b*) confined flow.

- Aquifer material has uniform permeability within the radius of influence of the well, and the aquifer is not stratified.
- For an unconfined aquifer, the saturated thickness is constant, and for a confined aquifer, the aquifer thickness is constant before pumping commences.
- The water table or the piezometric surface is horizontal.
- The well extends to the bottom of the aquifer and the pumping efficiency is 100 percent.
- Laminar flow exists within the radius of influence of the well.
- Steady-state conditions exist or, in other words, the shape of the cone of depression remains constant since both drawdown and radius of influence of the well do not change with a constant pumping rate.

From these assumptions, the following equations provide well discharge for steady unconfined radial flow and confined radial flow, respectively, toward a well:

$$Q - \frac{P(H_W^2 - h^2)}{1055 \log (R/r)} \tag{E.5}$$

$$Q - \frac{Pm(H_A - h)}{528 \log (R/r)} \tag{E.6}$$

where Q = well yield or pumping rate in gpm; P = permeability of water-bearing sand in gpd/ft^2, typically determined from laboratory or field tests; H_W = saturated thickness of the aquifer before pumping in feet; h = depth of water in the well while pumping in feet; R = radius of cone of depression in feet; r = radius of the well; m = thickness of aquifer; and H_A = static head at the bottom of the aquifer.

Equations E.4 and E.5 are for steady-state flow, that is, where discharge is constant with time. Because of the numerous factors affecting ground water flow, a long time may have to elapse before steady-state conditions are established. Therefore, the actual size and shape of the cone of depression can be obtained only after sustained periods of continuous pumping. Because of the variable composition of soils and climatic conditions, the actual time to steady-state flow is highly variable and may never exist. Additionally, several other factors impact well discharge, including proximity to other wells, presence of localized impermeable strata impeding flow to the well, anisotropic conditions leading to highly variable hydraulic conductivity, and large bodies of surface water.

Well Construction

Most wells are drilled and in some cases driven. There are two basic types of drilling methods used in well construction: cable tool and rotary. Other methods are variations of these two basic methods.

Driven Wells. Driven wells are constructed by driving a small-diameter pipe into shallow water-bearing sand, gravel, or other soft formations free from cobbles and boulders. A screened well point, attached at the bottom of the casing, acts as the intake portion. There are different types of well points to accommodate the various ground and aquifer conditions. In this type of method, selection of the appropriate well point is important to the success of the well. Ground water enters through the screen section and is pumped up through the casing. Although driven wells are simple and economical to construct, they are limited to depths of about 50 feet.

The Cable Tool Method. Sometimes referred to as the *percussion method,* this is the oldest method of well construction after hand digging. The method utilizes the action of lifting and dropping heavy drilling tools onto the bottom of the borehole in order to break and loosen the earth-rock material. The type of cable tool rig (see Figure E.5) and the size of the tool weight needed for well construction depend on the ground conditions and the depth of the hole.

As the drill bit breaks through the ground, the fragments of earth and rock must be removed so that the excavation can continue. The material is removed with a bailer—a section of pipe with a valve at the bottom and a bail at the top. As the bail is alternately raised and lowered, the valve is opened and closed, allowing the cuttings and fluid to enter the bailer. The bailer is hoisted to the surface once it becomes full and is then reinserted if additional cutting removal is necessary. Drilling operations resume after the bailing operation is complete. The well casing is then inserted into the hole after the drilling operations are complete.

The Rotary-Drilling Method. This method bores the hole with a rapidly rotating bit. An external force, which is applied to the bit as it is rotating, helps break the earth-rock material. Fluid, which is pumped into the borehole through the tool assembly, mixes with the cuttings and is pumped back to the surface through the annulus between the tool assembly and the sides of the borehole. A typical rotary drilling rig is shown in Figure E.6.

Cable tool drilling is less expensive than rotary drilling, lends itself to drilling in isolated areas, and has more reliable formation and water sampling. The resulting well is simpler, more durable, and virtually maintenance free. However, the limitations of this method, compared with the rotary drilling method, include shallower well depths, smaller well diameters, and a slower drilling time. The rotary drilling method produces an open borehole, which allows for a wider variety of casing and screen designs. Each method has its merits, and the one selected likely will depend on geologic conditions, site accessibility, and availability of supplies.

Well Components

Figure E.7 illustrates the various elements of a well structure. The well casing is the structural portion of the hole that supports the sides of the borehole, provides protection of the aquifer against contamination, and allows access to the aquifer. The casing must last for the life of the well,

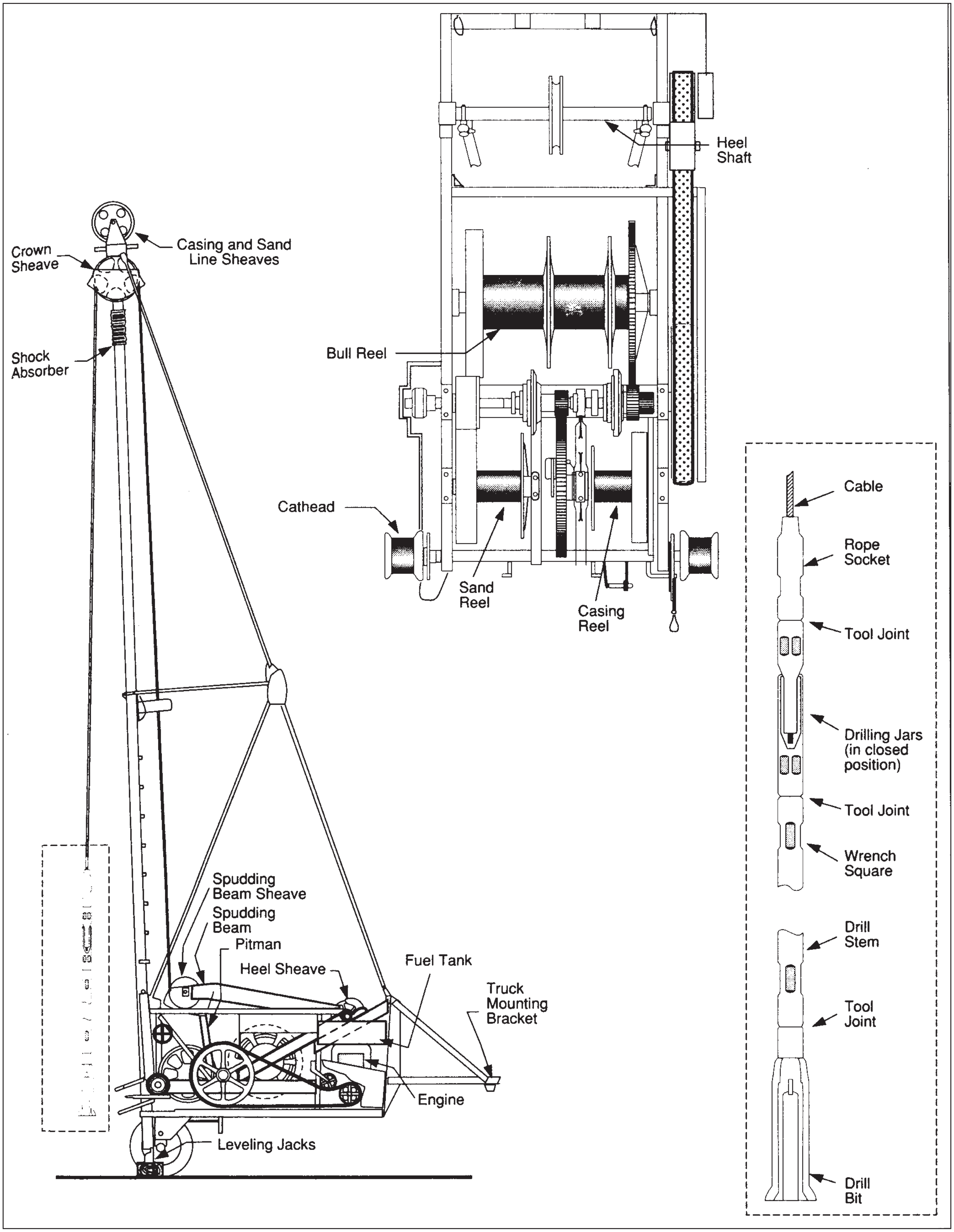


FIGURE E.5 Cable tool rig. (Courtesy of *Handbook of Ground Water Development,* Roscoe Moss Co. Reprinted by permission of John Wiley & Sons, Inc.)

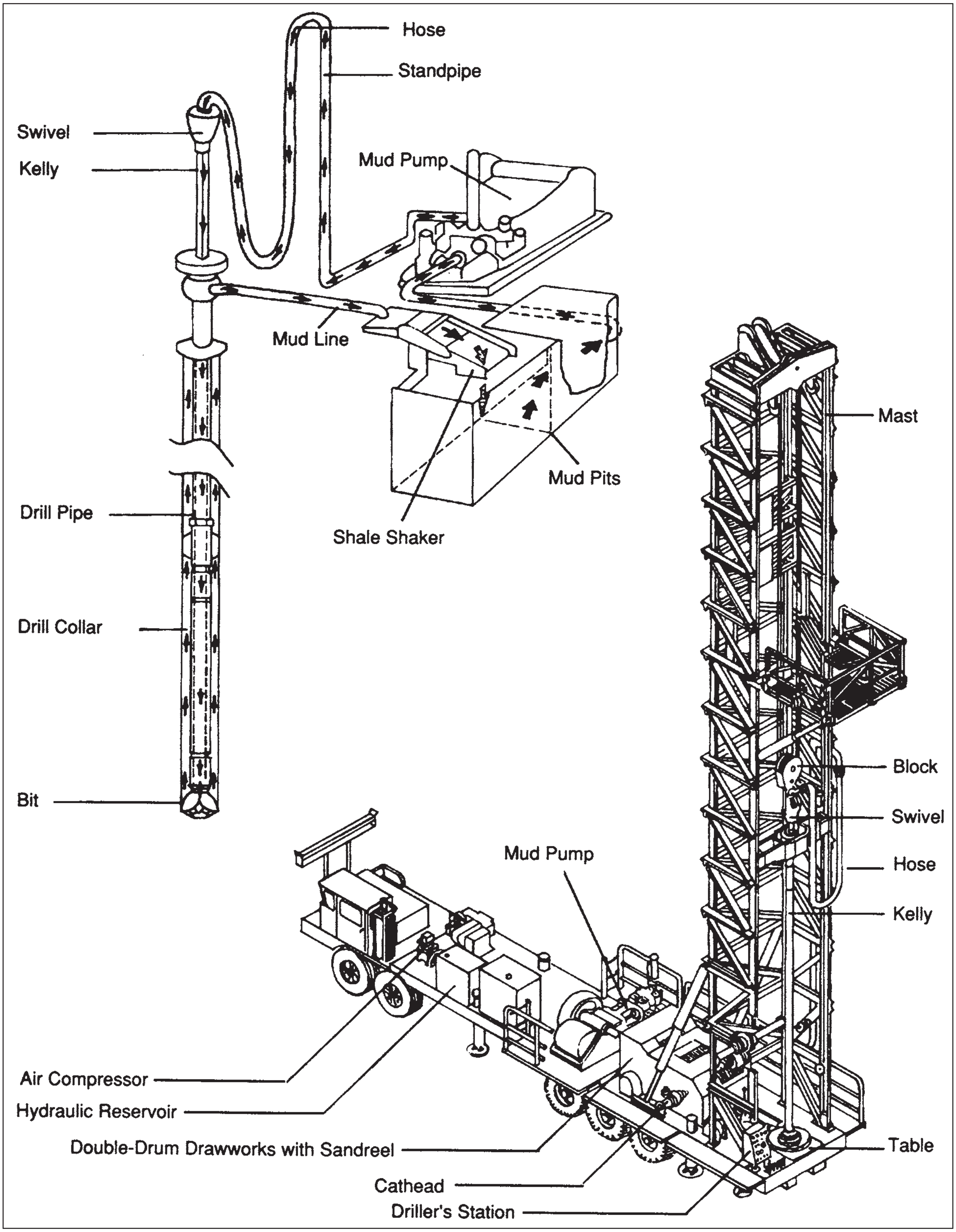


Figure E.6 Direct hydraulic rotary system. (Courtesy of *Handbook of Ground Water Development*, Roscoe Moss Co. Reprinted by permission of John Wiley & Sons, Inc.)

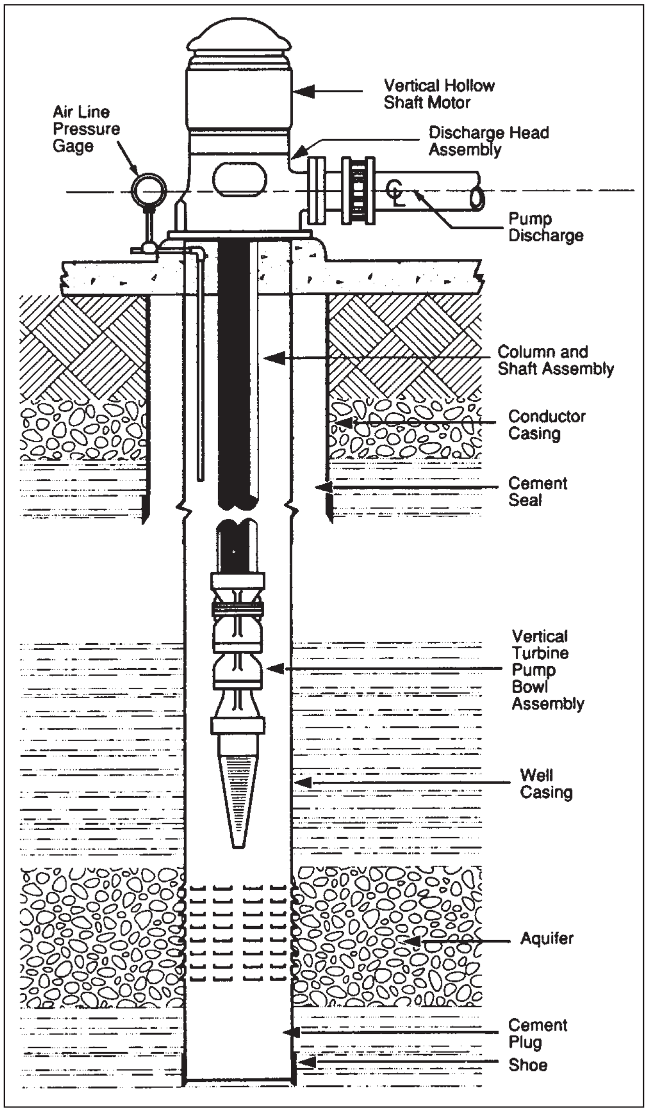


FIGURE E.7 Typical well installation. (Courtesy of *Handbook of Ground Water Development,* Roscoe Moss Co. Reprinted by permission of John Wiley & Sons, Inc.)

since replacing the casing inevitably causes some damage to the well.

Grout sealant is placed between the casing and the sides of the borehole to control vertical water movement and to protect the casing against deterioration.

The well intake for drilled wells is the screen and for driven wells is a well point. It is important to note that the length of the screen influences the capacity of the well far more than the diameter. This is demonstrated by Equation E.7, a form of the steady-state equation for the drawdown of an aquifer.

$$Q - \frac{Kbs}{528 \log\left(\dfrac{R}{r}\right)} \tag{E.7}$$

All things being equal, doubling the diameter of the well (r) results in approximately 10 percent increase in discharge. However, doubling the length of the screen intake directly results in a twofold increase in the discharge. The type of screen selected depends on the type of drilling, aquifer characteristics, and hydraulic characteristics. Various types of screens are shown in Figure E.8. In general, the screen length requirements for domestic wells are much less than those for municipal, commercial, or agricultural wells.

The well pump must be able to deliver the required pumping rate to meet the demand for the service area of the well. Typical individual domestic wells require approximately 5 to 20 gpm. Wells that serve a community of residences should provide a minimum of 0.5 gpm/dwelling, if storage is included in the design. If the aquifer is to serve large areas, auxiliary pumps may be necessary to maintain minimum pressures throughout the system. After the well is operating, a series of tests should be performed to determine the performance of the pump and well. To ensure proper performance of the well, periodic tests are necessary. The data from these tests, when compared with the original test data, can determine if the performance and efficiency falls within acceptable standards.

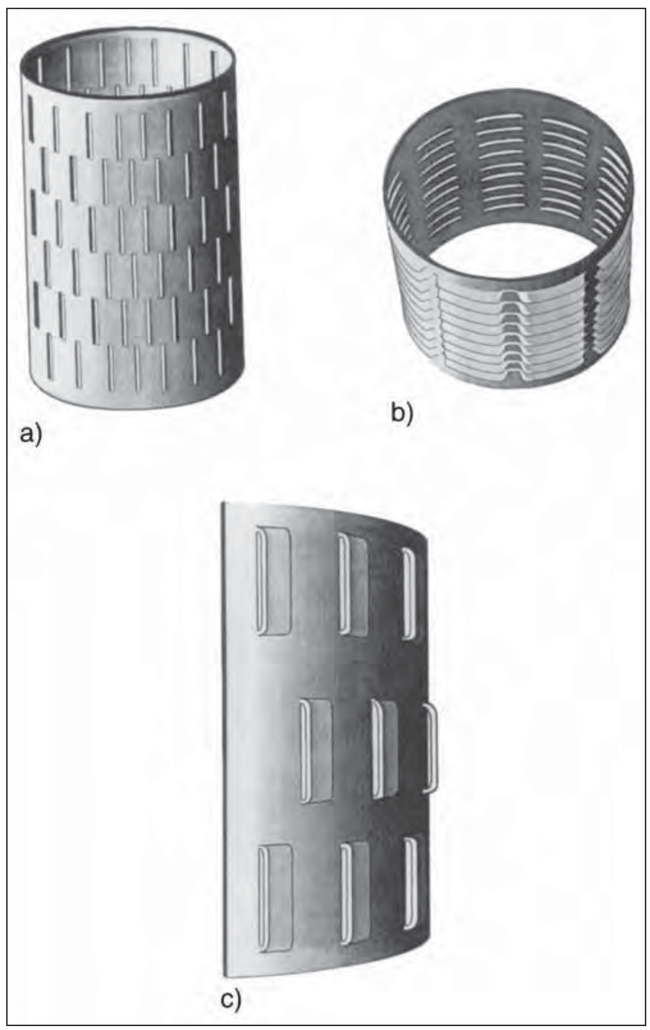


FIGURE E.8 Types of screen intakes: (*a*) vertical machine slotted screen; (*b*) shutter screen; (*c*) bridge slot screen. (Courtesy of *Handbook of Ground Water Development*. Roscoe Moss Co. Reprinted by permission of John Wiley & Sons, Inc.)

Ground Water Contamination

Before ground water can be used for consumptive purposes, it must be tested and approved by the state primacy and local authorities. In some locales, the developer needs such approval before any construction permits are issued. After the project is completed, state and local regulations may require periodic testing to ensure potable water quality standards. Treatment of the ground water may be necessary to remove (or reduce) some types of pollutants. In the extreme case, the water supply source may have to be abandoned. Site conditions may provide clues to potential ground water contamination. Following is a list of contamination sources, which may affect ground water quality:

- *Wastewater effluent:* The primary concern in semirural development projects is the relative location of the well to any subsurface wastewater disposal system. Typically, houses connected to wells also utilize a subsurface septic system. Water percolating from the drain field into the water table is a serious health hazard. To prevent this, the well should be located upslope and a minimum of 50 feet (horizontally) away from the disposal system.
- *Barnyard runoff:* Wells constructed downslope of barnyards and farmhouses present bacteria problems similar to those from household wastewater effluent. Bacteria from animal waste can infiltrate to the aquifer.
- *Pesticides and fertilizers:* Not only are farm fertilizers and pesticides a contaminant hazard, but many homeowners use fertilizers and pesticides on their lawns and gardens. Historically, many farms dumped the pesticide and fertilizer containers in wooded areas and pits. Similarly, orchards and vegetable lands are potentially hazardous areas with high concentrations of pesticides and fertilizers. Houses and wells may now stand in the vicinity of these disposal areas and crop lands. The decomposition or neutralization of the synthetic chemicals used in pesticides and fertilizers has not been fully determined.
- *Landfill areas:* Although present laws regulate the type of material that can be disposed of in a landfill, many closed landfills contain toxic chemicals that could cause long-term damage to the ground water.
- *Oil and gas fields:* Oil and gas fields present two potential ground water contamination hazards. The first potential problem arises from the fact that a by-product of oil/gas development is saline water. Most states have regulations on methods for disposal of this saline water to prevent ground water contamination. In the older oil and gas fields, saline water is escaping from improperly sealed wells and contaminating the ground water. Additionally, oil and gas production is increased by injecting saline water into the geologic cavity. The increased pressure in the cavity forces oil, gas, and saline water outward into the ground water.

This list emphasizes the need to verify the previous land uses on any proposed developments with well systems. The site analysis and inspection may provide clues to potential contamination hazards. Additionally, subsurface soil and water samples will verify suspicious areas. The types of contaminants associated with various land activities are identified in Table E.4. For water supplies already contaminated, the problem becomes one of pinpointing the type and location of the pollution source.

Table E.5 provides recommendations for minimum distances between contamination sources and wells. Due to the many factors that influence ground water movement, it must be recognized that there is no absolutely safe distance between a well and a contaminant source. Even though health department and local regulations dictate minimum distances, the engineer should consult specialists when conditions appear questionable. Table E.6 summarizes some possible remedies for specific ground water problems.

MTBE

Methyl tertiary–butyl ether (MTBE) has been a highly effective clean fuel additive for reducing air pollution from motor vehicles. Unfortunately, it has also contaminated community ground water supplies across the country. MTBE was first used in the late 1970s as an automobile fuel additive for premium-grade fuels to increase octave ratings. Starting in the 1990s, it was added in higher concentrations, as an oxygenate to enable more complete combustion in order to reduce carbon monoxide and other toxic air emissions. It readily dissolves in water and permeates rapidly through soils and aquifers. MTBE is more likely to contaminate ground water than other components of gasoline due to its resistance to microbial decomposition and mobility in water. The U.S. Geological Survey has reported that approximately 3 percent of ground water wells in areas of the country where MTBE has been used as a fuel additive have detection levels of 5 parts per billion (ppb) or above. Based on carcinogenic effects observed in laboratory animals, the action level for concern of potential cancer is 13 ppb. The best available technology for removal of MTBE is adsorption with granular activated carbon (GAC). Several states and Congress are considering legislation to eliminate MTBE as a gasoline additive as well as options that may prove to be effective in reducing air emissions without the potential for ground water contamination posed by MTBE.

SURFACE WATER SUPPLY

Surface water sources are usually more difficult, time consuming, and expensive to develop than ground water sources for small community potable water systems. Generally, when compared to ground water, developed surface water sources can provide significantly more water flow capacity over the lifetime of the system.

Surface waters, which are open to contamination from pollution, debris, sediment, and waterborne pathogens, usually require more extensive treatment than ground water sources. Legal rights to ground water are normally riparian, meaning they are acquired with title of the land overlying the water source. The rights to surface waters are more com-

TABLE E.4 Major Contaminants Associated with Waste Disposal Practices

SOURCE	POSSIBLE MAJOR CONTAMINANTS
Landfills	
Municipal	Heavy metal, chlorides, sodium, calcium
Industrial	Wide variety of inorganic and organic constituents
Hazardous waste disposal sites	Wide variety of inorganic (particularly heavy metals) and organic compounds (pesticides, priority pollutants, etc.)
Liquid waste storage ponds (lagoons, leaching ponds, recharge basins)	Heavy metals, solvents, inorganic compounds
Subsurface sewage disposal systems	Organic compounds (degreasers, solvents), nitrogen compounds sulfates, sodium, microbiological contaminants
Deep well waste injection	Variety of inorganic and/or organic compounds
Agricultural activities	Fertilizers, herbicides, pesticides
Land application (sludge, wastewater)	Heavy metals, inorganic compounds, organic compounds
Urban runoff infiltration	Inorganic compounds, heavy metals, petroleum products
Deicing activities	Chlorides, sodium, calcium
Radioactive wastes	Radioactivity and radionucleides

(From Hess, A.F., and J.E. Dyksen, *Utility Experiences Related to Existing and Proposed Drinking Water Regulations.* Reprinted from Annual Conference Proceedings, by permission. Copyright © 1984, American Water Works Association.)

plicated and vary widely from state to state. No development of any water source should be initiated until the rights to the water, including adequate withdrawal and use permits, have been successfully concluded.

Another advantage of surface water, besides its abundance (for large development projects), is its tendency to have less dissolved mineral content than ground water. The permitting process, however, is long and arduous in most states for either withdrawal from free-flowing streams or development of impoundments.

TABLE E.5 Distance from Sources of Contamination to Private Water Supplies

SOURCE	DISTANCE (FT)
Subsurface pits	50–75
Septic tank	25–50
Subsurface disposal fields	50–75
Sewage line	25–50
Seepage pits	50–100
Pasture	50–100
Barnyard	50–100
Farm silo	25–50
Petroleum or chemical Storage tank	50–100

Safe Yield

Once it is determined how much water will be needed for the planned development, initially and strategically for the future, potential sources can be evaluated for adequate production. Existing or potential lakes and reservoirs, rivers, and streams must be analyzed for safe yield. Safe yield is the amount of water that can be reasonably counted on for use by the community during drought conditions, assuming flowby requirements are met for maintaining downstream aquatic life and water-supported activities. Safe yield analyses are complex and require specialized expertise as well as assistance and considerable information from public agencies including such items as meteorological and hydrological data, the official definition of site-specific drought conditions and site-specific safe yield used by the jurisdiction, and the required permit conditions for surface water withdrawals.

Reservoirs and Lakes

To successfully use water supplied from a reservoir or lake, the following features must exist:

TABLE E.6 Ground water Problems, Causes and Remedies

Problem	Probable Cause	Remedy or Source of Help
Inadequate water yield	Poor aquifer Well screen or pump intake encrusted Lower water level	Install larger, deeper well; have well cleaned by well driller; deepen well; contact water resource agency
Wet basement	Seasonally high water table Recovered water level Drainage from roof or slope	Add sump pump or drains; add roof gutter, reslope land; contact SCS
Gas in water	Methane from bedrock state	Install vent on well head; aerate the water; install water treatment; drill new well away from house; contact geological survey
Salty water	Road salting Road-salt stockpile	Install new well farther upslope; provide better road drainage; install new well away from drainage; request correction by highway department; contact health department
Fuel-oil contamination	Leaky or spilled storage tank	Install new well upslope; adjust to low pumping rate
Oil/gasoline contamination	Nearby service station	Obtain new source of water; contact health department
Bacteria contamination	Septic effluent	Chlorinate as first step; contact health dept.; install new well upslope; install new leach field farther away; deepen well in some cases; seek control on neighboring system
Barnyard waste		Redirect waste flow; install new well upslope; seek control on neighbor's activity; contact agricultural agency
Organic chemical	Former land use contamination	Install new well farther away; deepen well in some cases; contact health department
	Current land application	Create a buffer zone around recharge area; dispose of wash water properly; seek control on neighbor's activity; contact health department
Land subsidence	Excessive ground water withdrawal Rock solution	Contact state regulatory agency; relocate house; contact state geological survey
Sinkhole development	Rock solution	Relocate house; contact state geological survey

(*Source:* Walter, R.M., *Ground water and the Rural Homeowner,* U.S. Geological Survey, 1988.

- The upstream watershed physical characteristics allow suitable water quality and quantity capacity.
- The watershed is protected by ownership, agreements with landowners, or state legislation.
- Adequate storage is available to allow settling of sediments and larger microorganisms prior to treatment.
- Adequate storage is available to allow sufficient supply during periods of drought.
- The intake design allows the highest-quality water available to be withdrawn for treatment.
- The stored water is treated to reduce the levels of turbidity, disinfection by product precursors, and microorganisms, and then is adequately disinfected.

The ideal impoundment watershed should be free of development and sewage systems, large enough to fill the reservoir during dry years, protected against erosion and drainage from livestock confinement areas, and fenced for the exclusion of livestock.

Development of a reservoir often involves the construction of an embankment with an overflow spillway. The services of qualified engineering and hydrogeological consultants are necessary to design the facilities and oversee their construction. For small systems, regulatory supervision and assistance are available from the National Resources Conservation Service (NRCS) and state or county agriculture, geological, or soil conservation agencies.

The intake facility design is vitally important to the successful operation of the water supply. If the water is drawn too close to the impoundment bottom, it may contain decaying organic matter or be too turbid. Water drawn from too near the water surface may contain algae, floating debris, or aquatic plants, resulting in taste and odor problems in the finished water. The depth of optimal intake varies with the configuration of the impoundment and the season of the year. Intake structures should be designed to provide flexibility for depth of withdrawal for optimal year-round operations.

Rivers and Streams

Dependable, year-round water supply is provided by various rivers and streams. When the only feasible source for some communities is a stream receiving runoff from a large, uncontrolled watershed, the water may be difficult and expensive to treat due to rapidly varying bacteriological and physical quality.

As with reservoirs, the intake facilities on rivers and streams must also be carefully designed. First, they should be located upstream of any sources of contamination such as wastewater discharges. Additionally, the intakes should be designed to exclude sediment and debris while allowing efficient withdrawal at varying stream levels. Often, the intake is designed with the features to protect it from high water levels, floating debris, and ice formation. On wide streams, it is often advantageous to locate the intake sufficiently offshore rather than at the bank. This design technique avoids turbid water from an upstream tributary, which typically flows along the bank of entry after a local storm event. Figure E.9 shows a typical prefabricated intake screen device commonly used on stream intakes. This device has an air blowback feature used to clear the screen of sediment and debris.

FIGURE E.9 Prefabricated stream intake. (Courtesy of U.S. Filter, Warrendale, PA)

To add all-season reliability to the water source, it may be necessary to implement an offstream storage reservoir. In this manner, water can be stored in times of heavy runoff and during high flows for use, as needed, when demands exceed available stream flow. The offstream storage can also be used when the stream source is of poor quality due to low flow or is contaminated due to a hazardous material spill.

The use of an infiltration-gallery-intake arrangement can also be of great benefit, especially when the stream is subject to extreme changes in turbidity from storm events. The infiltration gallery method of pretreatment is also referred to as *riverbank filtration*. Infiltration galleries are shallow, horizontal beds of natural or constructed permeable soils with collector pipes embedded in them that are situated adjacent to the water source. Additionally, they provide some pretreatment as a result of the natural filtration provided by the soil, which improves the source water quality. Although they are more commonly used for river and stream sources, they can be used to benefit reservoirs that are subject to events of heavy turbidity.

It should be noted that the use of an infiltration gallery to prefilter the source water does not preclude the need for further filtration and disinfection treatment. Even the waters of crystal-clear mountain streams have been found to contain serious health-threatening organisms, such as *Cryptosporidium* and *Giardia*.

WATER TREATMENT

The evolution of modern water treatment began in the early twentieth century, when the practices of filtration and chlorination disinfection became common. The main goal at that time was to remove (or inactivate) pathogenic organisms to curtail the disastrous waterborne disease outbreaks that routinely plagued the country during the previous century. This goal was achieved, as waterborne disease outbreaks were mostly eliminated in the United States by the 1930s. As a result, until fairly late in the century, the belief of the water industry was that microbiological contamination in surface waters could be successfully addressed with appropriate pretreatment, filtration to attain clarity of 1.0 turbidity unit (ntu) or less, followed by chlorination.

During this time, ground water was considered to be already filtered, requiring only the addition of chlorine to maintain a suitable residual in the distribution system. Any additional treatment performed was done solely to change characteristics unrelated to health such as hardness, taste, odor, and water coloration from manganese and iron. Consequently, the main challenge to water supply engineering in the 1960s and 1970s was to attain these simple treatment goals at the lowest operation and maintenance cost. As a result, new techniques were developed to clarify surface water more economically. These included new sedimentation basin designs, tube and plate settlers, dissolved air flotation, high-rate filtration processes, and preengineered proprietary package systems that integrated several basic processes into a single treatment unit.

Potential chronic (long-term) health risks from trace organic compounds in potable water became a public concern in the 1970s and 1980s. A new wave of regulations followed to set maximum containment levels (MCLs) for trihalomethanes (THMs), volatile organic compounds (VOCs), and pesticides. In response to this public concern, which continues to the present day, water engineers have successfully developed new treatment methods to remove organic compounds from drinking water. These new approaches, such as enhanced coagulation, air stripping, and activated carbon adsorption, were the main focus of water treatment engineering through the mid-1990s.

Microbiological contamination, however, has recently emerged (again) as the primary focus of the water treatment industry. The main causes of this development are: (1) documented cases of drinking water supplies contaminated by chlorine-resistant cysts such as *Cryptosporidium* and *Giardia,* and (2) the promulgation by the EPA of the Total Coliform Rule and the Surface Water Treatment Rule in 1989 and subsequent enforcement and monitoring actions. To address these new challenges, there is renewed emphasis on source water protection, treatment plant optimization, management of plant recycle streams, and implementation of newer technologies such as ozonation and membrane treatment.

Today's treatment system engineer must meet current drinking water standards and anticipate future regulatory requirements. No more is the definition of safe water a constant as it was in the 1950s, 1960s, and 1970s. The water industry will continue to struggle with capacity issues along with the potential health effects of traces of an ever increasing variety of organic compounds and infectious organisms. Now more than ever, a water treatment system must provide flexibility for modification in order to meet potential requirements.

A process schematic of a complete conventional surface water treatment system is shown in Figure E.10. The objective of water treatment is to provide high-quality, safe, finished water for long-term use. The processes used by treatment facilities to achieve this depend on the characteristics of the source water. As noted previously, surface water is likely to contain pathogenic organisms, organic substances, and particulate matter, while ground water may have undesirable mineral content or contaminants such as volatile organic compounds. The following processes are those often used in water treatment and are listed more or less in sequential order of occurrence in a water plant:

Pretreatment	Conventional filtration
Aeration	Membrane filtration
Coagulation	Adsorption
Flocculation	Disinfection
Sedimentation	Corrosion control
Softening	Fluoridation

These processes vary and overlap and would not all be appropriate for use in any single treatment plant for a surface or ground water source. Disinfection is the one process that would be used in all treatment systems for a community public water supply; however, there are different types of disinfection processes and combinations such as chlorine, chloramines, ozone, and ultraviolet (UV) light. The selection of water treatment and disinfection processes depends on the condition of the source water and regulatory requirements of the jurisdiction. It should be reiterated that the treatment process train outlined here and described in the following pages is applicable to both large- and small-scale operations.

Pretreatment

Pretreatment refers to any process that conditions the water prior to its entering the main treatment facility. For ground water, pretreatment is accomplished by natural filtering through aquifer sand and gravel layers, or through a gravel pack placed at the well screen intake. Chemical injection (usually hypochlorite) of ground water for pretreatment to control iron bacteria is sometimes necessary, while pretreatment for surface water consists of screening as a minimum. Presettling in an offstream reservoir, for example, can provide more consistent raw water turbidity, making treatment operations less variable and complex. Nuisance aquatic organisms such as algae, weeds, and zebra mussels can interfere with treatment processes and cause unpleasant tastes and odors in the finished water. Exclusion of sunlight from the intake structure and judicious application of copper sulfate to the impoundment have been effective in controlling algae. Physical screening and cleaning are normally the most cost-effective means for controlling aquatic weeds and animals.

Aeration (Air-Stripping)

Uses of aeration as a means of treatment are:

- Removal of volatile organic compounds (VOCs)
- Removal of radon gas
- Removal of substances that may interfere with downstream processes (i.e., removal of carbon dioxide from water prior to lime softening)
- Oxidation of iron and manganese so they can be removed by downstream processes
- Reduction of concentrations of substances that cause undesirable tastes and odors, and oxidation of organic matter

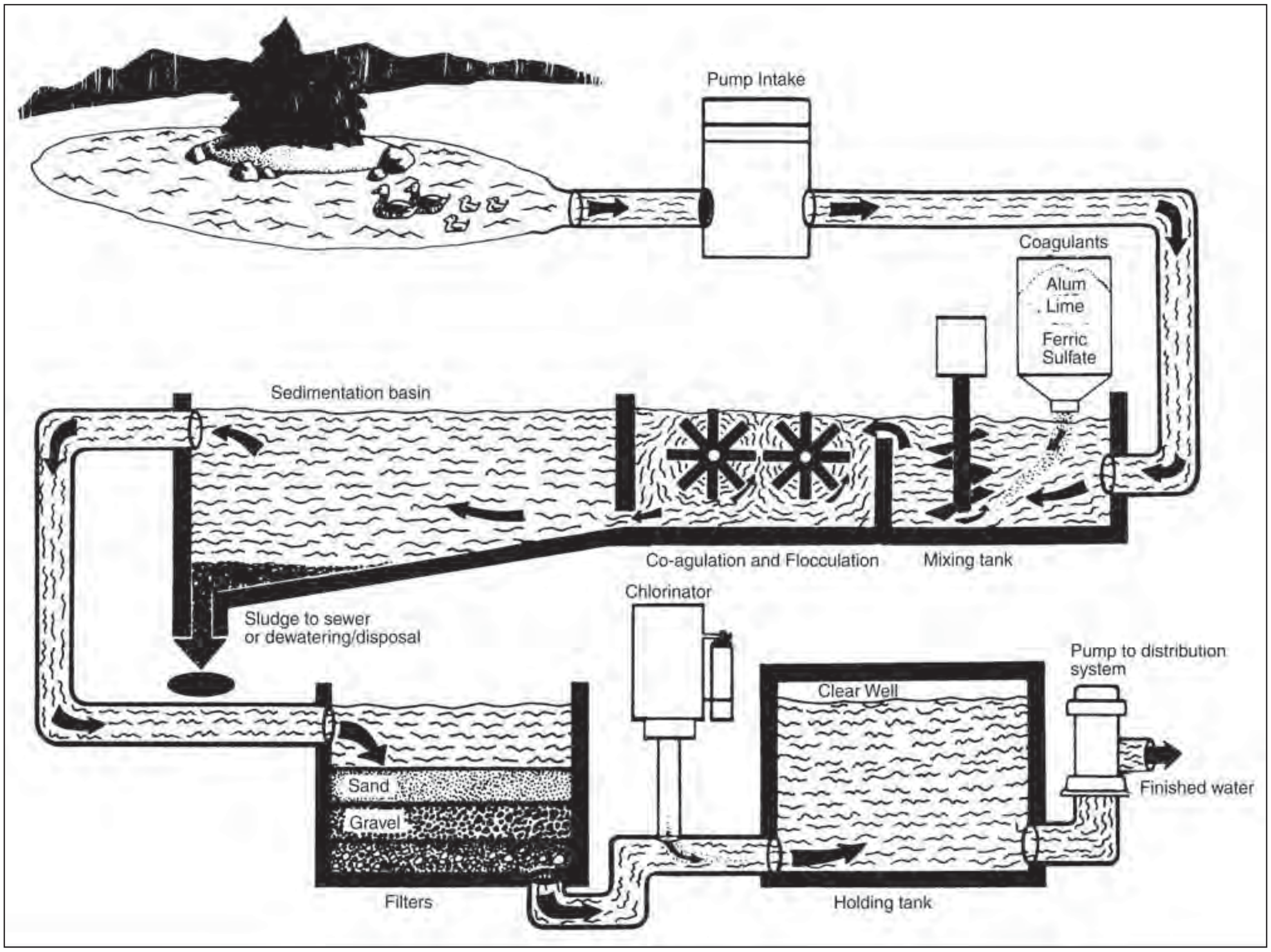


FIGURE E.10 Typical surface water treatment plant schematic. (Courtesy of Purae Engineering, Inc.)

Aeration can be accomplished in any number of ways including waterfall or cascade, diffused air, mechanical aeration, and pressure aerators (adding air to water under pressure).

Coagulation

Coagulation is the process of adding chemicals to raw water that cause an almost instantaneous reduction of the forces that tend to keep particles separated. Coagulant chemicals routinely added to destabilize particles are alum, ferric salts, lime, and cationic organic polymers. The coagulation process is also known as *rapid mixing* or *flash mixing*. The purpose of flash mixing is to provide uniform, instantaneous dispersion of the coagulant chemical throughout the influent raw water to condition it for subsequent removal of particles. Rapid mix is achieved by introducing the chemicals at a point of maximum agitation, such as at a static mixer. *Enhanced coagulation* is a term coined by the EPA in the Disinfectants and Disinfection By-Products Rule. This rule requires that the coagulation process of some water supplies be operated in order to provide removal of a specific percentage of organic material from raw water as measured by total organic carbon (TOC). This enhanced removal of TOC is usually achieved by increasing the dosage of coagulant chemical or by adjusting the raw water pH during the coagulation reaction.

Flocculation

Flocculation is the agglomeration of small particles and colloids to form larger particles (flocs) that can be settled or filtered. Incidental flocculation begins in the zone of decaying mixing energy of the rapid mixing step (that destabilized the forces that keep particles separated). In some instances, this incidental flocculation may be adequate. However, a separate flocculation process is usually included in the process flow train to build floc to optimum size, density, and strength. Sometimes a separate aid, such as a cationic, anionic, or nonionic polymer, is added in the flocculation process to achieve greater floc density. Baffles, slow-moving paddles, or gentle aeration, which provide velocity gradients that promote particulate contact (without floc shearing agitation), are used in conventional plants.

Sedimentation

During sedimentation, suspended material begins to settle out of the water due to gravity. Some water plant settling basins have mechanical collectors for solids removal and disposal. When there are no solids collectors, multiple basins must be provided so that each basin can periodically be taken out of service for solids removal. Detention time is not usually an important design parameter for modern sedimentation basins. It is more important that sedimentation basin inlets are baffled properly to prevent short circuiting (see Figure E.11), and that they are designed for proper surface loading rates (see Table E.7). The efficiency of modern sedimentation basins is often enhanced with either tube settlers or lamella plates (see Figure E.12). These devices allow sedimentation basin space requirements to be greatly decreased. Consequently, these devices are very popular for use in preengineered package plant units, while still remaining popular for use in large water plants.

Softening

Water softening is the process by which minerals, mainly calcium and magnesium, are removed from water. Softening also removes metals and other water constituents, and is commonly used when hard water scaling is a problem. The processes by which water is softened include lime–soda ash, ion exchange, and membrane treatment. Note that both ion exchange and lime–soda ash processes increase the sodium content of the finished water. This fact must be considered for those customers on low-sodium diets. Lime and soda ash react with the various calcium and magnesium salts (bicarbonates) to form two insoluble precipitates, calcium carbonate and magnesium hydroxide, which are removed by sedimentation and filtration. If sodium hydroxide (caustic soda) is substituted for lime, less sludge is produced, a consideration when sludge disposal costs are high. However, caustic soda is more expensive than lime and increases the total dissolved solids contents in the treated water. Additionally, it is a hazardous chemical that may not be appropriate for small systems employing part-time personnel. Lime and soda ash softening, with certain adjustments at large plants, also provides removal of color and turbidity.

A more appropriate process choice for water softening in small systems is probably ion exchange. Ion exchange is used by small community systems with ground water sup-

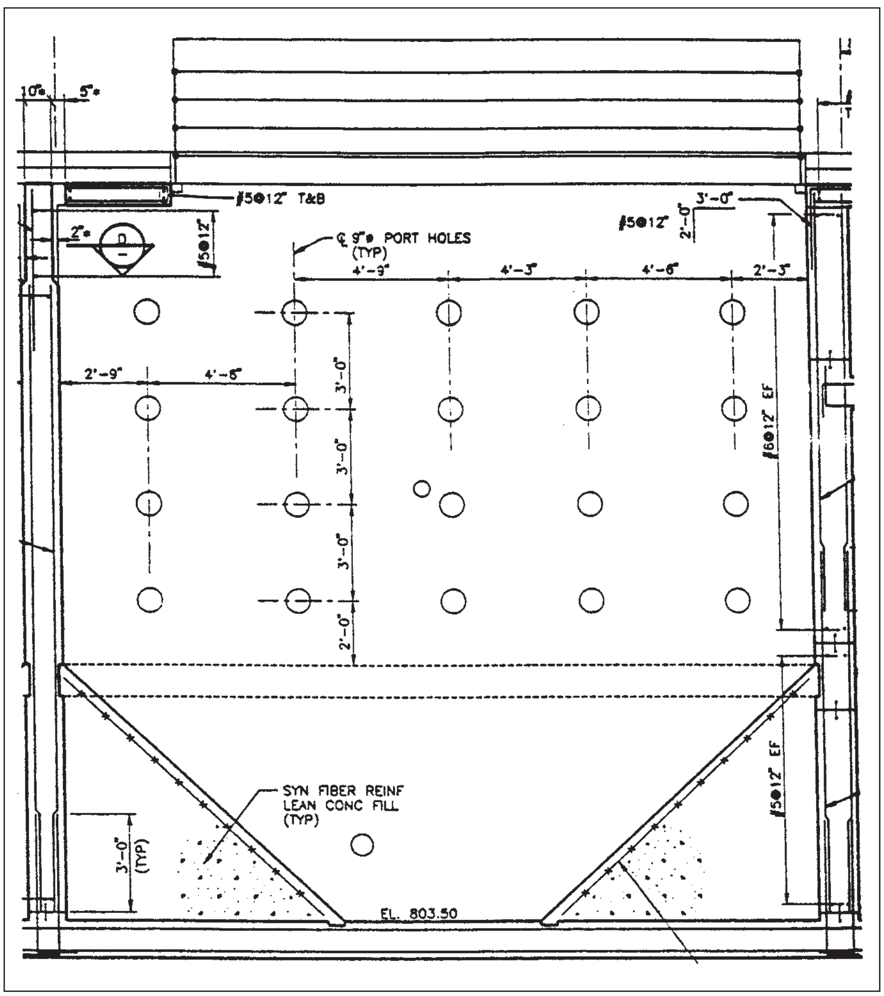


Figure E.11 Typical inlet baffle across rectangular clarifier in section. (Reprinted from *Water Treatment Plant Design,* 3rd ed., 1990, McGraw-Hill, New York)

TABLE E.7 Typical Sedimentation Surface Loading Rates Using Alum Coagulation

APPLICATION	GPD/FT^2
Turbidity removal	800–1200
Color and taste removal	600–1000
High algae content	500–800

(Reprinted from *Water Treatment Plant Design,* 3rd ed., 1990, McGraw-Hill, New York.)

plies and in household softeners. Softening is provided by replacing (or exchanging) hardness ions in the water with sodium ions, which is accomplished by flowing hard water through a vessel containing polystyrene resins (see Figure E.13). The calcium and magnesium ions, within the water, attach to the resin, which releases sodium ions. The resins must be periodically regenerated by adding a saltwater sodium chloride solution to the vessel; to replenish the sodium ions a small wastewater stream requiring disposal is created. Ion exchange has also become popular in recent years for small community water systems, since it also is useful in removing nitrate from ground water supplies.

Potassium chloride, as a substitute for sodium chloride in water softeners, is becoming more popular due to environmental considerations. A small amount of potassium in drinking water can be beneficial to users, while sodium can be harmful for users on salt-sensitive diets. There is also some concern that sodium damages septic tank drain fields and deteriorates the quality of ground water after recharge. The only disadvantage with potassium chloride is that it presently costs nearly twice as much as sodium chloride.

Conventional Filtration

Conventional filtration, as applied to water treatment, is the passing of water through a filter media to remove suspended solids. Filtration remains one of the fundamental processes of water treatment, with recorded use as early as 4,000 BC. The effectiveness of filtration is determined by measuring the turbidity of the filtered water. Turbidity is a light-scattering property of suspended particles in water measured in turbidity units (ntu). Since most of the turbidity within highly turbid surface source water is removed by processes preceding filtration, the solids load on the filters is reduced, making them more cost effective to operate. Filters must produce a high-quality effluent to ensure that disinfection of the finished water is effective. Filtration greatly improves water quality, but is only one of several major barriers against contamination in finished potable water. Ground water that is low in iron and manganese, and not contaminated by surface influence, may not require filtration; however, all surface waters must receive filtration as required by the SDWA Surface Water Treatment Rule. The types of filters that may be used are slow sand, rapid sand, diatomaceous earth, bag, and cartridge. All must be followed by effective disinfection.

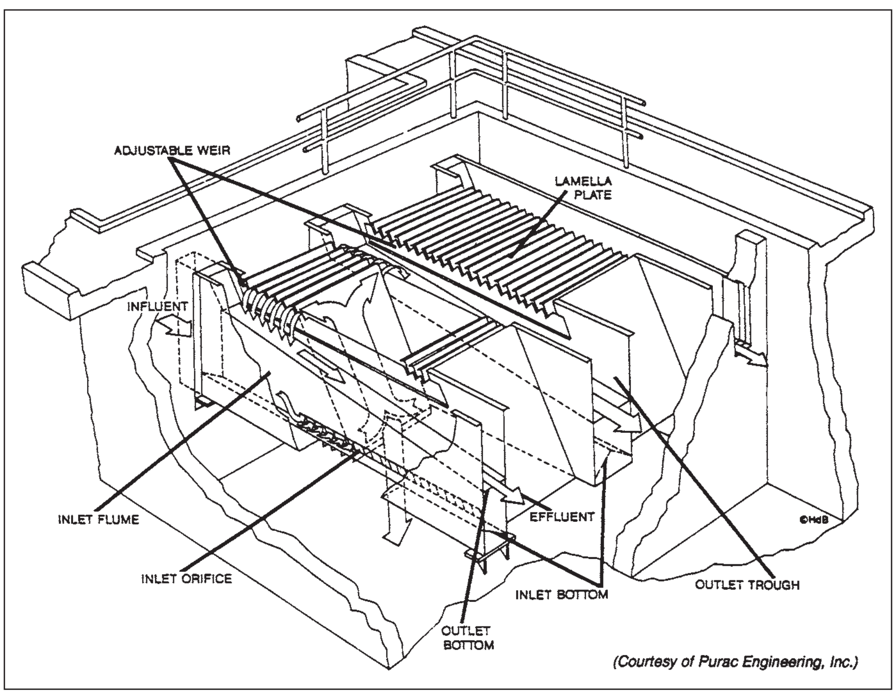


FIGURE E.12 Plate settlers. (Courtesy of Handbook of Ground Water Development, Roscoe Moss Co. Reprinted by permission of John Wiley & Sons, Inc.)

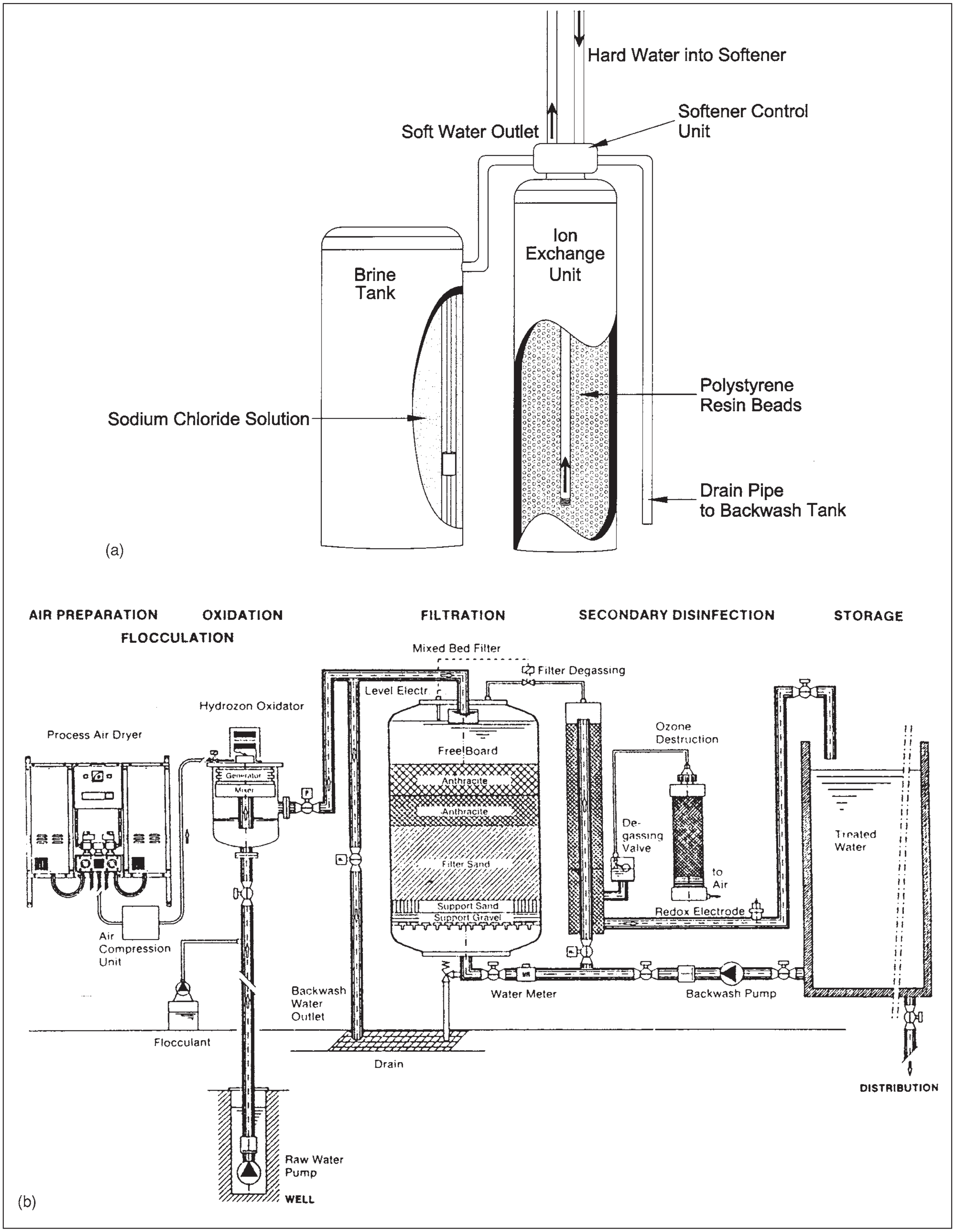


FIGURE E.13 Schematics of (*a*) basic ion exchange unit; (*b*) ion exchange treatment system. (Courtesy of National Drinking Water Clearinghouse, Morgantown, WV)

Slow Sand Filters. For slow sand filtration, water is passed through beds of fine sand at light loading rates averaging 0.05 gpm/ft^2. Although much more filter bed area is needed for slow sand filtration than for other methods, this may not be that significant for small plants. Since the sand is not backwashed in place, the top inch of its surface is periodically removed and replaced with clean sand. The removed sand is usually discarded, but can be washed and stockpiled for replacement later. Slow sand filtration does not require extensive pretreatment with chemicals, but works best in waters that are not excessively turbid or have highly variable turbidity. It is normally preceded with presettling in an impoundment, as a minimum. Slow sand filters periodically slough biological material, as they are biological processes. The time period between removals of the top layer of sand depends on the turbidity of the water. Multiple beds are needed so some may be cleaned while others remain in service. The use of this method has become less common as more mechanically intensive means have become increasingly reliable.

Rapid Sand (High-Rate) Filters. This method is the most commonly used means of filtration for both large and small water plants in the United States. Filtration beds of sand or sand and anthracite coal, usually supported on beds of gravel, are loaded at rates of 2 to 10 gpm/ft^2. The filters are cleaned by backwashing finished water in the reverse direction through the filters after filter runs of 12 hours to 15 days. If using this technique with a surface water source, the surface water must receive coagulation, flocculation, and clarification before high-rate filtration.

High-rate filters can be either gravity units or pressure units. For pressure units, the water is pumped through an enclosed pressure vessel that contains the filter media. This type of unit is often used by small utilities with ground water sources.

Diatomaceous Earth (DE) Filters. DE filters can be in either pressure or vacuum vessels. The filter media is diatomaceous earth, the skeletal remains of small single-cell organisms in seawater called diatoms. DE filters are backwashed every several hours; the backwash process removes the media along with the accumulated solids. The filters must then be precoated with new DE prior to the next filter run. During a run, DE media is continually added to the influent water to maintain the filtering surface in optimal condition. DE filters, which were used extensively for small systems from the 1970s to early 1990s, are waning in popularity due to the development of less complex package plants and membrane processes.

Bag and Cartridge Filters. Bag and cartridge filters have been used for years in industrial water treatment applications, but are becoming more practical for use in small municipal systems. For bag filtration, disposable bags made from materials of a specific pore size are supported in a housing as water flows through them for removal of particulate matter. Typically, bags are used in stages from larger to smaller pore size, and are replaced and discarded once maximum operating pressures are reached due to solids accumulation.

The arrangement and operation of cartridge filters are similar to those of bag filters in that they are housed in canisters in multiple stages of porosity and are disposable once excessive operating pressures are reached. The cartridges are of rigid construction, usually made of ceramics or cotton fibers.

Membrane Technology

A semipermeable membrane is a thin layer of material that has the capability of separating substances when a driving force is applied across it. Membrane technology was once considered viable only for desalinization. However, advances in membrane production and module design have greatly contributed to the decline in capital and operating costs of such facilities for water treatment. These installations are increasingly being employed for removal of bacteria, other microorganisms, and particulate and natural organic matter (that causes taste and odors and reacts with disinfectants to form undesirable organic by-products). The capital cost of membrane treatment (on a dollar-per-volume treatment capacity basis) does not rapidly increase as treatment capacity decreases as it does with conventional water treatment. This allows membrane technology to be cost effective for small systems.

Indeed, the National Research Council, in a 1997 report, concluded that membranes will be used with accelerating frequency in small systems as the complexity of conventional treatment processes increases to meet new regulatory requirements. As an example, for ground water sources not needing pretreatment, membrane treatment facilities consist of little else than holding tanks, membrane modules, and feed and cleaning pumps. However, waste streams for membrane technologies are 15 percent or more of inflow, while conventional treatment waste streams are 5 to 10 percent. This is a significant consideration where waste stream disposal is a difficult problem.

Traditional water treatment has focused on liquid-solid separation rather than the removal of dissolved contaminants from water that is possible with membrane technologies. The 1996 Safe Drinking Water Act (SDWA) amendments encouraged the use of membrane treatment alone or in combination with conventional liquid-solid separation to meet the more stringent requirements (see Table E.8). Membrane processes used in water treatment are electrodialysis, reverse osmosis, microfiltration, ultrafiltration, and nanofiltration.

Electrodialysis. This process has been widely used for desalinization of brackish water. Unlike other membrane processes that use high pressure to force water through a membrane, electrodialysis uses electrodes to pull positive and negative ions from the water through selective membranes. Since only charged ions are removed, the range of constituents removed is much narrower than, for example, in reverse osmosis. Electrodialysis is effective in removal of fluoride and nitrate and can also be used to remove selenium, barium, and cadmium. Its waste stream, however, is

TABLE E.8 Membrane Technology Compliance with the Surface Water Treatment

UNIT TECHNOLOGIES	REMOVAL: LOG GIARDIA AND LOG VIRUS	RAW WATER, PRETREATMENT, AND OTHER WATER QUALITY ISSUES	COMPLEXITY: EASE OF OPERATION (OPERATOR SKILL LEVEL)	SECONDARY WASTE GENERATION	OTHER LIMITATIONS/ DRAWBACKS
Microfiltration (MF)	Very effective giardia, >5–6 log; partial removal of viruses (disinfect for virus credit).	High quality or pretreatment required. Same note regarding TOC.	Basic: increases with pre/posttreatment and membrane clearing needs.	Low-volume waste may include sand, silt, clay, cysts, and algae.	Disinfection required for viral inactivation.
Ultrafiltration (UF)	Very effective giardia, >5–6 log; partial removal of viruses (disinfect for virus credit).	High quality or pretreatment required (e.g., MF). TOC rejection generally low, so if DBP precursors are a concern, NF may be preferable.	Basic: increases with pre/posttreatment and membrane cleaning needs.	Concentrated waste: 5 to 20% volume. Waste may include sand, silt, clays, crysts, algae, viruses, and humic material.	Disinfection required for viral inactivation.
Nanofiltration (NF)	Very effective, absolute barrier (crysts and viruses)	Very high quality or pretreatment required (e.g., MF or UF to reduce fouling/extend cleaning intervals). See also RO pretreatments.	Intermediate: increases with pre/posttreatment and membrane cleaning needs.	Concentrated waste: 5 to 20% volume.	Disinfection required under regulation and recommended as a safety measure and residual protection.
Reverse osmosis (RO)	Very effective, absolute barrier (crysts and viruses)	May require conventional or other pretreatment for surface water to protect membrane surfaces: may include turbidity or FE/MN removal; stabilization to prevent scaling; reduction of dissolved solids or hardness; pH adjustment.	Intermediate: increases with pre/posttreatment and membrane cleaning needs.	Briney waste. High volume, e.g., 25 to 50%. May be toxic to some species.	Bypassing of water (to provide blended/ stabilized distributed water) cannot be practiced at risk of increasing microbial concentrations in finished water. Post-disinfection, required under regulation, is recommended as a safety measure and for residual maintenance. Other posttreatments may include degassing of CO_2 or H^2S and pH adjustment.

Source: Courtesy of National Drinking Water Clearinghouse, Morgantown, WV

20 to 90 percent of influent flow, and it has a relatively high capital and operating cost since it requires a high level of pretreatment. For these reasons it is not appropriate for consideration for most small community systems except for special applications such as for brackish water.

Reverse Osmosis. Pressure, as high as 300 lb/in^2 depending on the application, is used to force water through a semipermeable membrane in the reverse osmosis (RO) process. Nearly all (96 percent) inorganic contaminants are left on the high-pressure side as water passes through the molecular structure of the membrane. RO is also effective for removal of natural organic substances, pesticides, radium, and microbiological contaminants. If used in series, RO can achieve contamination concentrations of nearly zero. To prevent membrane fouling, filtration pretreatment is usually required as a minimum, while sometimes chemical additives, softening, or both are needed. Note that compact commercial package RO units are available that include all the pretreatment equipment. These units require only minimal labor and are simple to operate, making them suitable for small systems, especially when there are extremes in seasonal water demand.

Nanofiltration, Ultrafiltration, and Microfiltration. These pressure-driven membrane technologies differ only in the pore size of the membranes and can be used alone or in combination, depending on the water quality goals. These three processes are sometimes referred to collectively as membrane filtration. Microfiltration uses the largest pore size of the three for removal of particulate matter and microbes in the 0.05 to 10 μm size range. It is not, however, able to remove soluble constituents. Ultrafiltration is also used for liquid solids separation, but can also remove ionic organic material (based on molecular weight) and viruses since its size operating range is 0.001 to 0.05 μm. Both ultrafiltration and microfiltration operating pressures are from 10 to 100 lb/in^2. Nanofiltration, which uses operating pressures from 75 to 150 lb/in^2, removes particles as small as 1 nanometer. Nanofiltration is very effective in removal of color and disinfection by-product precursors and can remove ions contributing to hardness (such as calcium and magnesium).

Adsorption

Adsorption (in water treatment) refers to a process by which the water is brought in contact with a material for attraction and adhesion of gas, liquid, or dissolved substance to a surface. The adsorptive material most suitable for organic containment removal, including taste- and odor-causing compounds, is granular activated carbon (GAC). The EPA has designated GAC as the best available technology for removal of synthetic organic chemicals (volatile organic compounds, for example). Carbon is available in two forms: powdered activated carbon (PAC) and granular activated carbon.

Powdered activated carbon can be fed, dry or in a slurry, early in the treatment process and later removed in downstream processes. PAC is typically used in treatment plants to occasionally address taste and odor problems. GAC is used when continuous treatment is necessary. GAC is commonly used as a filter media, either as a top-layer supplement to the filter bed or as a replacement for filter media in a normal filter bed or special contactor tank. The contactors can be either gravity or pressure units similar to those used in conventional filtration. The GAC must be periodically removed and replaced with new or regenerated carbon when its absorptive capacity is expended.

Disinfection

The SDWA Surface Water Treatment Rule (SWTR) requires disinfection of finished water for public systems with surface water sources or ground water sources under the influence of surface water. Disinfection is arguably the most important step in making sure that water is safe to drink. The primary means of disinfection are chlorination, ultraviolet light, and ozone.

Disinfection (in the water utility industry) is referred to as primary and secondary. Primary disinfection is achieved as part of the treatment process, and secondary disinfection is done to ensure the distribution system is protected against microbial contamination or regrowth. Chlorine and compounds of chlorine are by far the most popular means of disinfection, since they provide both primary and secondary residual disinfection. Using ultraviolet light is not as effective as using chlorine (or ozone) at inactivating *Cryptosporidium* and *Giardia,* and no chemical disinfectant has been totally reliable in inactivating *Cryptosporidium* oocysts. The best available treatment method for this pathogen is still physical removal and multiple treatment processes.

Chlorination. Chlorination is most commonly provided by gaseous chlorine, sodium hypochlorite, or calcium hypochlorite. Chlorine is effective against almost all microbial pathogens and is appropriate as both the primary and the secondary disinfectant. Figure E.14 shows a typical arrangement for a cylinder-mounted chlorinator for a 150-pound chlorine gas cylinder typically used in small water plants. At least two of these arrangements with automatic switchover apparatus (for when one cylinder becomes empty) are usually provided. Since chlorine gas in air is lethal even at small concentrations, special housing, monitoring, safety equipment, and trained personnel are necessary.

Calcium hypochloride is a white solid available in tablet, granular, or powder form, which dissolves easily in water. The tablets are designed for use in commercially available feeding apparatuses that add tablets to plant flow based on flow rate or time. The powder and granular forms are commonly used to make a stock solution that is then metered into the plant flow at desired application points. Since calcium hypochlorite is highly corrosive, it must be kept away from organic materials such as wood or cloth, as contact may cause a heated reaction and fire. This chemical readily absorbs moisture and releases chlorine gas. Shipping containers should be emptied completely and carefully resealed.

Another chemical commonly used for chlorination disinfection for small water systems is sodium hypochlorite. Although highly corrosive, sodium hypochlorite solution is less difficult to handle than either calcium hypochlorite or gaseous chlorine. Sodium hypochlorite is available in solution form in concentrations of 5 to 15 percent chlorine. Since sodium hypochlorite solutions deteriorate, they should not be stored more than one month even in an ideal cool, dry, and dark place. This chemical is more expensive than gaseous chlorine, although the cost is significantly reduced if bulk deliveries by tanker truck can be made to an on-site storage tank. This may not be practical for small systems due to the relatively short shelf life of the solution.

Chloramine forms when ammonia is added to chlorinated water or when water containing ammonia is chlorinated. It is a weak disinfectant for use against viruses and protozoa compared to free chlorine, but chloramination produces less disinfection by-products. This makes chloramine appropriate for use as a secondary disinfectant to prevent bacterial regrowth in the water distribution system. Chloramine is commonly developed and applied by injecting ammonia gas (or ammonia hydroxide solution) into the flow stream just downstream of where chlorine is applied.

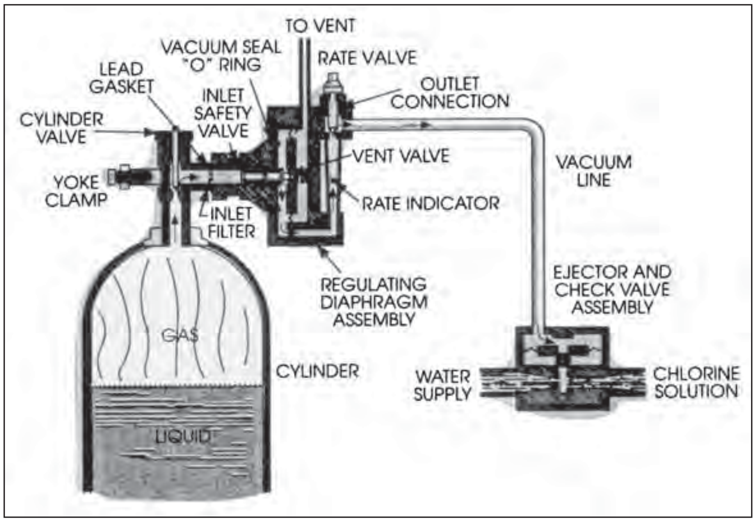


FIGURE E.14 Cylinder mounted chlorinator. (Courtesy of National Drinking Water Clearinghouse, Morgantown, WV)

The chemical reactions of water treatment through chlorination are somewhat complex. A discussion of some of the associated terminology follows for clarification:

■ *Chlorine dosage* or feed rate is the amount of the disinfectant fed into the treatment flow stream expressed in mg/L, or parts per million (ppm), which are equivalent. The water being treated has impurities that combine with some of the chlorine. These impurities, such as organic matter or ferrous iron, exert a chlorine demand that necessitates increased dosage to both satisfy this demand and provide chlorine for disinfection. Chlorine left over for disinfection is referred to as *available.*

■ *Combined available chlorine residual* refers to compounds of chlorine that have some disinfectant properties that are formed when chlorine reacts with ammonia or other nitrogen compounds. Chloramine, previously discussed, is an example. The most effective disinfectant form of chlorine is *free available chlorine residual.* This is the uncombined chlorine that remains in the water after any combined residual has formed. *Total available chlorine residual* is the total concentration of chlorine compound available to act as a disinfectant, including both combined and free chlorine residuals.

■ *Chlorine contact time* (CT) is the period of time from when chlorine is first applied and when the chlorinated water is used. The contact period required to ensure effective disinfection depends on chlorine dosage, type of chlorine residual, temperature, and pH of the water. The SDWA SWTR requires that, before the water reaches a consumer, chlorine dosage be adequate to fulfill chlorine demand and provide free available chlorine residual after chlorine contact time has been satisfied.

The SWTR requires certain minimum CT values, where the residual concentration C of a disinfectant in mg/L is multiplied by the contact time T in minutes. State agencies with primacy to enforce the SWDA rules can provide particular details and requirements for CT calculations. These calculations often require that additional finished water storage tankage be installed, or that existing tankage be baffled to prevent short-circuiting. This is to ensure that the disinfectant has adequate contact time before the first customer uses the water.

Ultraviolet Light (UV). Ultraviolet light radiation is produced by a special lamp arranged so that it irradiates water as it flows by (see Figure E.15). It provides disinfection by penetrating the cell wall of an organism to disrupt the genetic material such that it is no longer able to reproduce. UV is very effective in destroying viruses and bacteria in water, and can be used as a primary means of disinfection. However, it provides no residual effect, and a secondary disinfectant must be used in conjunction with UV to prevent microorganism regrowth in distribution systems. UV disinfection produces no known toxic residual and requires only a brief contact time. It is not, however, suitable for water with elevated turbidity, suspended solids content, color, or soluble organic matter that can interfere with the passage of light. UV radiation is not reliably effective against *Giardia* or *Cryptosporidium* cysts, so they must be physically removed from the flow by upstream processes.

Ozonation. Like UV, ozonation provides no residual, and a secondary disinfectant (such as chlorine) must be used with it to protect against pathogens in the distribution system. However, ozone is a powerful primary disinfectant that requires a shorter contact time and lower dosage than chlorine.

Ozone is generated by passing dry air through high-voltage electrodes to form a powerful disinfecting and oxidizing agent. It is unstable and, therefore, must be generated on-site. It has a low solubility in water and must have an effi-

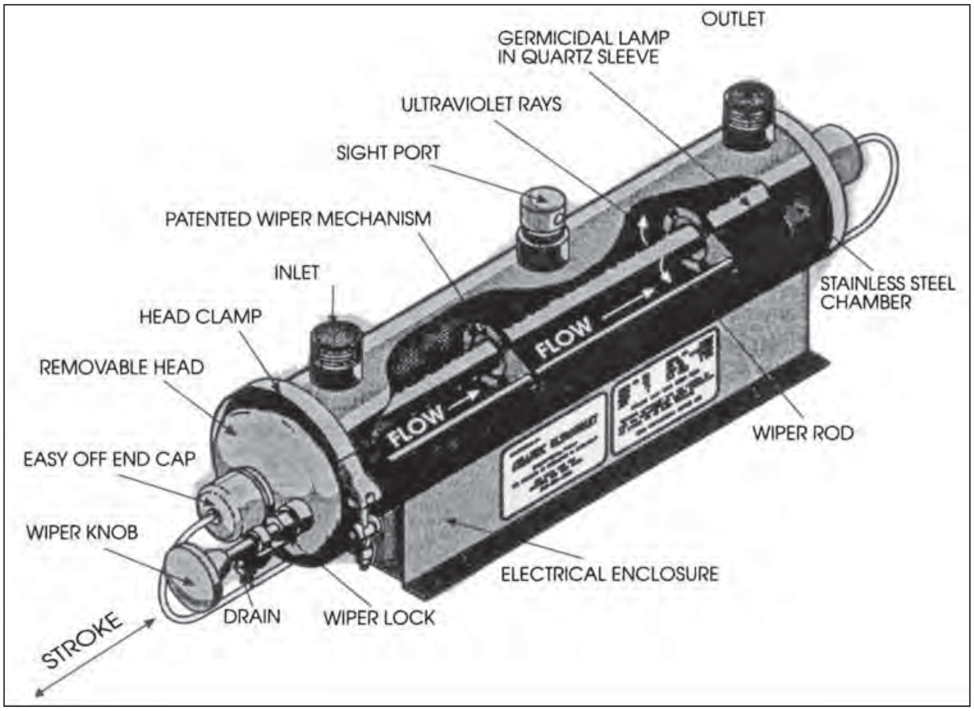


FIGURE E.15 Ultraviolet water purifier. (Courtesy of National Drinking Water *Clearinghouse,* Morgantown, WV)

cient contact arrangement. Even so, an excess ozone destruction unit is necessary to prevent this toxic gas from being released from the contractor near operations personnel.

Figure E.16 shows a schematic diagram of typical ozone treatment for a small water system. Ozone package units are available for small water plants, but power consumption is high and operation and maintenance are fairly complicated and costly. Ozonation can produce some undesirable halogenated organic materials, but much less than disinfection by chlorination.

Corrosion Control

Corrosive water attacks the structural integrity of the distribution system, causing leaks and adverse impacts on the finished water aesthetics. It also causes trace quantities of hazardous metals, mostly lead and copper, to be leached from both the distribution system and household fixtures into the consumable water, potentially impacting the health of consumers. The lead and copper rule of the SDWA requires a testing program based on population, and actions to reduce corrosiveness of the water when testing indicate it is needed. Corrosiveness can be reduced by changing the characteristics of the water. Common methods are alkalinity and pH adjustment and lime softening. Chemical handling and feeding facilities need to be included in treatment facilities with adverse water characteristics.

Fluoridation

Fluoridation of water to reduce tooth decay in children is a common practice in the United States. The three chemicals used for this purpose are sodium fluoride, fluorosilic acid, and sodium fluorosilicate. Fluorosilic acid is available as a corrosive liquid, while the other two are available in crystalline or granular form. These chemicals can be fed by solution or dry feeders, and the dosages must be carefully controlled. Too much fluoride can cause teeth to become pitted and mottled, while too little has no effect.

Residuals Disposal

Some of the water treatment plant processes generate residual waste streams that require plans for handling and disposal facilities during the treatment process design. Some treatment processes result in residuals that are not particularly difficult to handle. For example, debris separated by initial raw water screening, such as leaves and limbs, can be taken to conventional solid waste landfills. Residual sludges formed when suspended solids in the source water are coagulated and settled can be disposed of in a variety of ways. They can be discharged to a sanitary sewer, if available; dewatered by a mechanical device (i.e., sludge press or centrifuge); or discharged to a lagoon. However, decant from sludge lagoons discharged to surface water must have a National Pollution Discharge Elimination System (NPDES) permit. The solids held in lagoons must eventually receive final disposal. They can either be hauled in liquid form to be applied on land or be processed at a wastewater treatment plant. Lagooned solids that have been held long enough will become dewatered sufficiently so that they can be excavated and hauled to landfills or permitted land application sites.

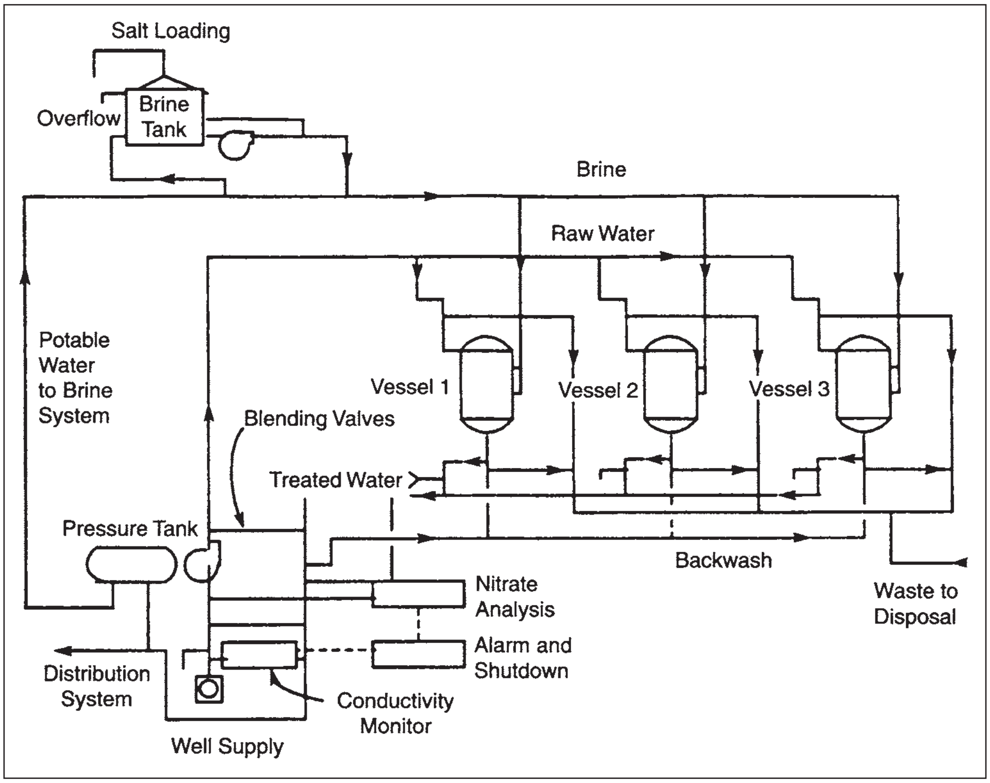


Figure E.16 Schematic of a system that provides primary disinfection with ozone, filtration, secondary disinfection, and excess ozone gas destruction. (Courtesy of National Drinking Water Clearinghouse, Morgantown, WV)

As drinking water quality becomes more stringently regulated, it is reasonable to expect that required contaminant removal levels will continue to increase. This will result in the use of more complicated treatment processes and more complex, concentrated, and possibly hazardous residuals. For example, brines resulting from ion exchange media regeneration and solids from plants treating water with radionuclide content may require special permits and handling methods for disposal.

Package Plants

Package plants offer many advantages over conventional in-ground custom treatment plants for small systems. The main difference between custom and package plants is that package units are factory assembled and mounted on skids for transport to the site, while custom plants, as the name implies, are constructed at the site. Not only are the package units more economical to construct, but they are specifically designed to minimize operation attention. This makes them ideal for small systems where full-time, trained operators are not usually available.

Package plants are appropriate in plant sizes from 25,000 gpd to 6,000,000 gpd. They can be used to treat ground water for contaminants, such as iron and manganese, or surface water with a wide range of characteristics. The influent water quality is the most important consideration when selecting a package unit. However, package units are designed to treat water in a certain range of parameters, and it is important to select the appropriate unit for the range of influent characteristics of the water to be treated.

The SDWA has greatly increased interest in package units for small communities. Construction and maintenance of conventional custom plants that meet the new regulations pose financial challenges that can be somewhat relieved by use of package plants instead.

Package units, which are able to compactly incorporate conventional processes, are widely used in small systems to treat surface and ground water sources. However, many of the advanced processes are also available in package units, which can be used in combination with conventional processes to provide comprehensive water treatment.

There are considerably positive indications in the water industry literature and marketplace of an increasing number of competitive, modern, and technically impressive water treatment package plants available to support land development projects. The consulting engineer responsible for designing the water treatment facilities for land development projects would do well, when considering treatment options, to review package plants comprehensively and strongly consider the latest assortment of available units for best performance, economy, and overall results. To select a package plant, pilot testing to evaluate treatment processes and operations on a small scale in relation to site-specific conditions is recommended and often required.

PRACTICAL CONSIDERATIONS

Project Schedule

In addition to addressing available resources, needs, and characteristics of the individual site and the pertinent regulations, the land development consultant is often the driver when it comes to construction progress—making sure permits are procured on time, inspections are scheduled and completed, and facilities are ready and available for occupancy. Construction timing and water supply availability can be affected significantly when items such as easements are not processed promptly, field inspections are not performed on schedule, terrain and grade controls are not well established, space allocation for all utilities is not well organized within recorded easements and rights-of-way, and coordination communications and well-planned construction sequences are not emphasized. This point is stressed because the coordination and scheduling of the regulatory, inspection, and installation elements and controls, in many cases, take considerably more time than the direct construction and installation effort indicated in the engineering plans and specifications. Given the various tasks—the coordination, protocols, and sequence of events required to meet standards and control the sanitation features of supplying potable water—and number of involved parties, increased due diligence is warranted by all parties to keep this type of project on schedule.

For example, project design and schedule considerations must incorporate time to conduct site-specific evaluations and treatment plant testing as required when on-site treatment processes are used. Pilot plant testing evaluates the treatment process design by constructing a small-scale operating model to simulate the full-scale treatment process train. The pilot plant operates at much lower flows, but it allows important evaluations of the treatment process train performance prior to investing in the full-scale plant. In addition to obvious economic reasons to test prior to full-scale commitments, more specific reasons and purposes include:

- Comparing alternative treatment processes
- Solving treatment process problems by investigating process modifications
- Investigating new treatment processes
- Demonstrating confidence in recommended treatment processes
- Meeting regulatory requirements
- Establishing design criteria

Pilot plants can typically be constructed or placed inside an existing facility, shop, warehouse space, or a small field office trailer—often in spaces less than 8 ft × 16 ft. Pilot testing often takes a year, given the merits of testing the treatment processes during all seasons and weather conditions. In some cases, the regulators may waive or alter aspects of the pilot test study if similar waters have been successfully pilot tested. In some instances, package treatment equipment manufacturers may perform these tests among others, another benefit of this type of installation, especially for smaller treatment facilities where resources may be at a premium.

Maintenance and Monitoring

Private Well Monitoring. As expressed earlier, some small developments with less than 15 service connections will go forward using private drinking water wells and will not be regulated under the SDWA. In such cases, well owners, including household well owners, should have their water tested periodically (recommended at least annually) for total coliform bacteria, nitrates, total dissolved solids, and pH levels plus any other suspected contaminants. State-certified laboratories should perform all testing. Test results can be compared to federal and state drinking water standards by contacting the EPA Safe Drinking Water Hotline (800-426-4791), the state health department, or the state department that provides environmental protection services. More frequent testing may be warranted if special conditions or unique concerns arise (see Table E.9). Such situations might include someone in the facility or household having a special medical condition or being pregnant or nursing, a facility occupant or family member with an unexplained illness, a suspected or reported contaminant in a neighborhood well or in the aquifer, noticeable water taste or odor changes, a change in appearance—color or clarity, and when well systems are constructed, repaired, or replaced.

Watershed and Wellhead Protection. Once a source water is identified—be it surface water or ground water—land development project stakeholders and individual households have various joint interests and common due diligence needs and objectives in protecting their respective investments and property interests. One common need is keeping the water source and its contributing watershed or aquifer from becoming polluted. Watershed and wellhead protection is one of the requirements of the 1996 SDWA amendment.

Watershed protection includes smart land use planning that accounts for community development needs and the availability, sustainability, and protection of natural resources to support such development. Best management practices (BMPs) for stormwater management and erosion and sediment control reduce pollution from construction and development. Green building efforts—increasingly common in both the private and the public sector down to the level of individual homes—seek to reduce water demand and consumption by building occupants, thus taking a multifaceted approach to watershed protection and long-term sustainability.

Generally, the steps of a wellhead protection program include identifying land area that needs to be protected, assessing the potential contamination threats, and designing and implementing strategies to address the contaminant sources such as public awareness and education programs and the development of contingency and emergency plans.

TABLE E.9 Reasons to Test Your Water

Conditions or Nearby Activities:	Test For:
Recurring gastrointestinal illness	Coliform bacteria
Household plumbing contains lead	pH, lead, copper
Radon in indoor air or region is radon rich	Radon
Corrosion of pipes, plumbing	Corrosion, pH, lead
Nearby areas of intensive agriculture	Nitrate, pesticides, coliform bacteria
Coal or other mining operations nearby	Metals, pH, corrosion
Gas drilling operations nearby	Chloride, sodium, barium, strontium
Dump, junkyard, landfill, factory, gas station, or dry-cleaning operation nearby	Volatile organic compounds, total dissolved solids, pH, sulfate, chloride, metals
Odor of gasoline or fuel oil, and near gas station or buried fuel tanks	Volatile organic compounds
Objectionable taste or smell	Hydrogen sulfide, corrosion, metals
Stained plumbing fixtures, laundry	Iron, copper, manganese
Salty taste and seawater, or a heavily salted roadway nearby	Chloride, total dissolved solids, sodium
Scaly residues, soaps don’t lather	Hardness
Rapid wear of water treatment equipment	pH, corrosion
Water softener needed to treat hardness	Manganese, iron
Water appears cloudy, frothy, or colored	Color, detergents

Source: U.S. EPA, 2002

Water System Capacity Development. Among the many regulatory activities stemming from the SDWA and the 1996 updates is a means of addressing the development, status, and performance of existing and future water systems by assessing their viability and sustainability. A method has progressed with the EPA carefully and comprehensively defining *water system capacity* and *water system capacity development. Capacity* is defined by the EPA as the “water system’s ability to consistently provide safe drinking water for its customers. To do that, a water system must have the technical abilities, managerial skills, and financial resources to meet state and federal drinking water regulations.”

Enforcement of capacity and capacity development is facilitated by an EPA national policy allowing the withholding of federal funds to the States’ Drinking Water State Revolving Fund (DWSRF). States can avoid funding reductions by adequately documenting ongoing development and implementation of capacity development strategies for water systems. Small systems and their communities often depend on the DWSRF for loans and grants for capital improvement projects. Capacity development strategy is part of the process that is applied to all systems, existing and future, notwithstanding type, size, or whether its source is ground water or surface water. Capacity development, with its method of defined terminology, meanings, and strategies, is insightful and illustrative of existing and potential future concerns, emphases, and approaches by the industry to address water system sustainability issues.

Security

Fundamentally, water industry operations necessitate security measures to protect the public from contamination while providing continuous service regardless of system size, large or small. The U.S. Department of Homeland Security, the EPA, and the water industry promote capacity development, sustainability, and an “all hazards” approach for continuous operations notwithstanding the type of threat. The EPA has published and distributed National Drinking Water Advisory Council Recommendations on Water Security that include the features and recommended measures to assess effectiveness of a utility’s security program (see Table E.10).

TABLE E.10 Recommended Measures to Assess Effectiveness of a Utility's Security Program

FEATURES	POTENTIAL MEASURES OF PROGRESS	
Organizational Features		
Feature 1—Explicit commitment to security	Does a written, enterprise-wide security policy exist, and is the policy reviewed regularly and updated as needed?	X
Feature 2—Promote security awareness	Are incidents reported in a timely way, and are lessons learned from incident responses reviewed and, as appropriate, incorporated into future utility security efforts?	X
Feature 5—Defined security roles and employee expectations	Are managers and employees who are responsible for security identified?	X
Operational Features		
Feature 3—Vulnerability assessment up-to-date	Are reassessments of vulnerabilities made after incidents, and are lessons learned and other relevant information incorporated into security practices?	X
Feature 4—Security resources and implementation priorities	Are security priorities clearly identified, and to what extent do security priorities have resources assigned to them?	X
Feature 7—Contamination detection	Is there a protocol/procedure in place to identify and respond to suspected contamination events?	X
Feature 10—Threat-level-based protocols	Is there a protocol/procedure of responses that will be made if threat levels change?	X
Feature 11—Emergency response plan tested and up-to-date	Do exercises address the full range of threats—physical, cyber, and contamination—and is there a protocol/procedure to incorporate lessons learned from exercises and actual responses into updates to emergency response and recovery plans?	X
Feature 14—Utility-specific measures and self-assessment	Does the utility perform self-assessment at least annually?	X
Infrastructure Features		
Feature 6—Intrusion detection and access control	To what extent are methods to control access to sensitive assets in place?	X
Feature 8—Information protection and continuity	Is there a procedure to identify and control security-sensitive information, is information correctly categorized, and how do control measures perform under testing?	X
Feature 9—Design and construction standards	Are security considerations incorporated into internal utility design and construction standards for new facilities/infrastructure and major maintenance projects?	X
External Features		
Feature 12—Communications	Is there a mechanism for utility employees, partners, and the community to notify the utility of suspicious occurrences and other security concerns?	X
Feature 13—Partnerships	Have reliable and collaborative partnerships with customers, managers of independent interrelated infrastructure, and response organizations been established?	X

Source: U.S. EPA—Water Security

CONCLUSION

The consultant providing water supply and treatment services has a vital role strategically, starting early on in the planning process as well as during design and construction, and throughout the life cycle of the project, in terms of providing potable water services to the community. Regardless of whether a land development project hinges on the use of individual household or community wells, a drinking water treatment package plant, construction of a new treatment plant, or connecting to an established water system, the value of carefully identifying and selecting the most appropriate option along with the technical oversight and management of the project's construction and operations will undoubtedly continue to grow in importance in the days ahead, short term and strategically.

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APPENDIX F

CASE STUDY: MERRIFIELD TOWN CENTER

Lisa N. Rauenzahn, PE, LEED AP

PART I: INTRODUCTION TO MERRIFIELD TOWN CENTER

Merrifield Town Center (MTC) is constructed on an assemblage of parcels totaling 7.48 acres located west of Gallows Road (Rt. 650) and south of Lee Highway (Rt. 29) in Fairfax County, Virginia. Just under one mile from the Dunn Loring metro station, this suburban redevelopment project was the first phase of the Town Center. Originally zoned Industrial (I-5) and Highway Corridor (HC), the site was rezoned to Planned Residential Mixed-Use (PRM) to allow 105,500 ft^2 of retail and office space and 270 residential condominiums, including 14 affordable dwelling units (ADUs), for a gross floor area of 440,000 ft^2. Total costs for the project approached $135,000,000.

Located in a comprehensive plan designated Town Center area, the site urban design concept was clearly a pedestrian-friendly approach to redevelopment. Although all parties endeavored to create a "pedestrian experience," it quickly became evident with the completion of the traffic study that extensive access improvements would be required to accommodate projected traffic scenarios stemming from the ultimate Town Center and to maintain the public street network internal to and surrounding the site.

Striking a balance between vehicular and pedestrian demands became the primary site design factor. From conceptual design through final engineering and construction, Dewberry worked closely with the client, neighbors, and local jurisdiction staff to plan and engineer a site that provided required public improvements with as little compromise to the urban design guidelines as possible. As the first phase of redevelopment in the Town Center, MTC was a precedent-setting project in this part of the county, where substantial change was envisioned in terms of public infrastructure enhancements, economic opportunities, and community lifestyle options.

PART II: FEASIBILITY AND SITE ANALYSIS

Developer's Perspective: Market Needs and Community Vision

The old adage "location, location, location" is entirely applicable to Merrifield. According to Michael Collier, president of Uniwest (developer), "Merrifield is a unique area in Fairfax County because it is the midpoint of the Tyson's Corner–Fairview Park Office Complex/Inova Hospital barbell." With two substantial employment centers north and south of the site, quick access to the Capital Beltway (495) and Route 66 (a major east-west corridor), and proximity to the orange line metro stop at Dunn Loring, Merrifield is a nexus for redevelopment in Fairfax County. (See Figure F.1.)

The highly industrial nature of Merrifield was truly an underutilization of this prime location; without a more pronounced residential component and complementary commercial services to support it, this area would remain a transit corridor between the two employment centers rather than the vibrant community many locals, businesses, and county officials wished to create. In the late 1990s, local business and citizen's groups successfully spearheaded several changes to the county comprehensive plan to facilitate the transition from highly industrial to moderately dense mixed use.

Local to Merrifield, Uniwest had a vested interest in the progress of the Comprehensive Plan amendments and played an active role in the many public charettes and meetings. While it was clear the site had potential, it was impor-

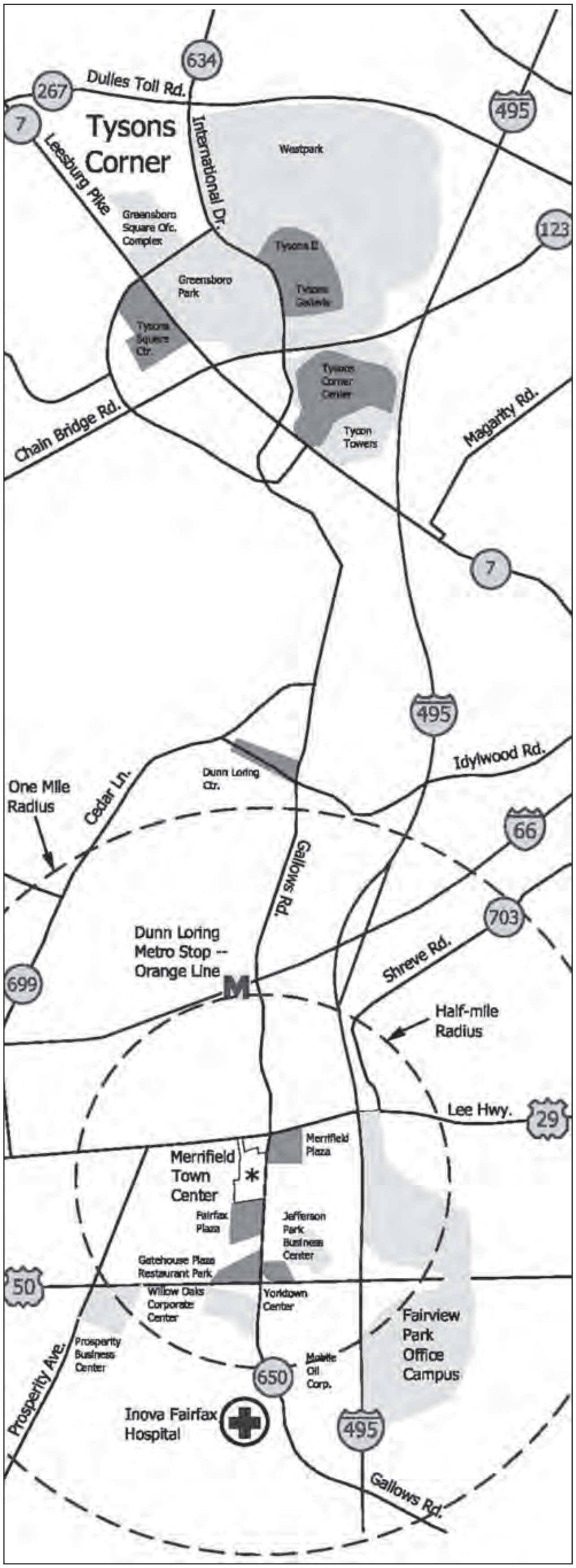


FIGURE F.1 Vicinity map—Merrifield Town Center.

tant to ensure that the developer's vision meshed with the community's vision and was accounted for in the plan amendment.

During this process, multiple scenarios were reviewed by the design team—namely, by the developer—in terms of economic feasibility. Scenarios ranged from different usage mixes to different types of residential applications (rental apartment versus condominium), to property size insomuch as parcel acquisition opportunities (for surrounding/adjacent parcels) were in flux. Through iteration and refinement, the design team identified the opportunities and constraints of various development scenarios and worked progressively toward a highest and best use examination. Dewberry's familiarity with Fairfax County, paired with the adaptability and creativity inherent to this process, resulted in quick, continuous feedback and ultimately enabled Uniwest to make programming, go/no-go decisions, and proffered commitments with confidence and faith that the program could be delivered in subsequent steps of the development process.

Feasibility (Site Assessment)

Environmental Considerations. Given the existing zoning and uses on the site including warehouse storage, a dry cleaner/laundromat, truck rental facility, and temporary car storage lot, there were several environmental concerns during the initial site investigation. Numerous monitoring wells were located in the southeast portion of the site; these wells served as an indicator of prior contamination and cleanup. Subsequent and more detailed investigation during the course of the Phase I environmental site assessment (by others) revealed little cause for concern, and the site was cleared for redevelopment. Because the site was already developed, noteworthy natural resources did not exist. Several trees located on adjacent property were identified for cautionary reasons, and recently planted material was designated as possible transplant material. Located at the very upstream end of the Accotink Creek watershed, there was no evidence of wetlands or federally regulated water bodies, and the site is not in a floodprone zone. Cultural resources were not present on the site or in close proximity. (See Figure F.2.)

Engineering Considerations. Because the site is located in a highly developed part of Fairfax County, engineering feasibility analysis focused on existing utility capacity, access and circulation issues, grading, drainage, and stormwater management, in particular, outfall adequacy.

The site was serviced by existing utilities including water, sewer, storm drain, gas, and electric. Initial inquiries to utility providers proved valuable, identifying the following host of design considerations.

- Although located in Fairfax County, water service for this area is provided by the City of Falls Church. Capacity was not an issue; however, as a result of this unique scenario, an additional jurisdiction became involved in the plan review and approval process.

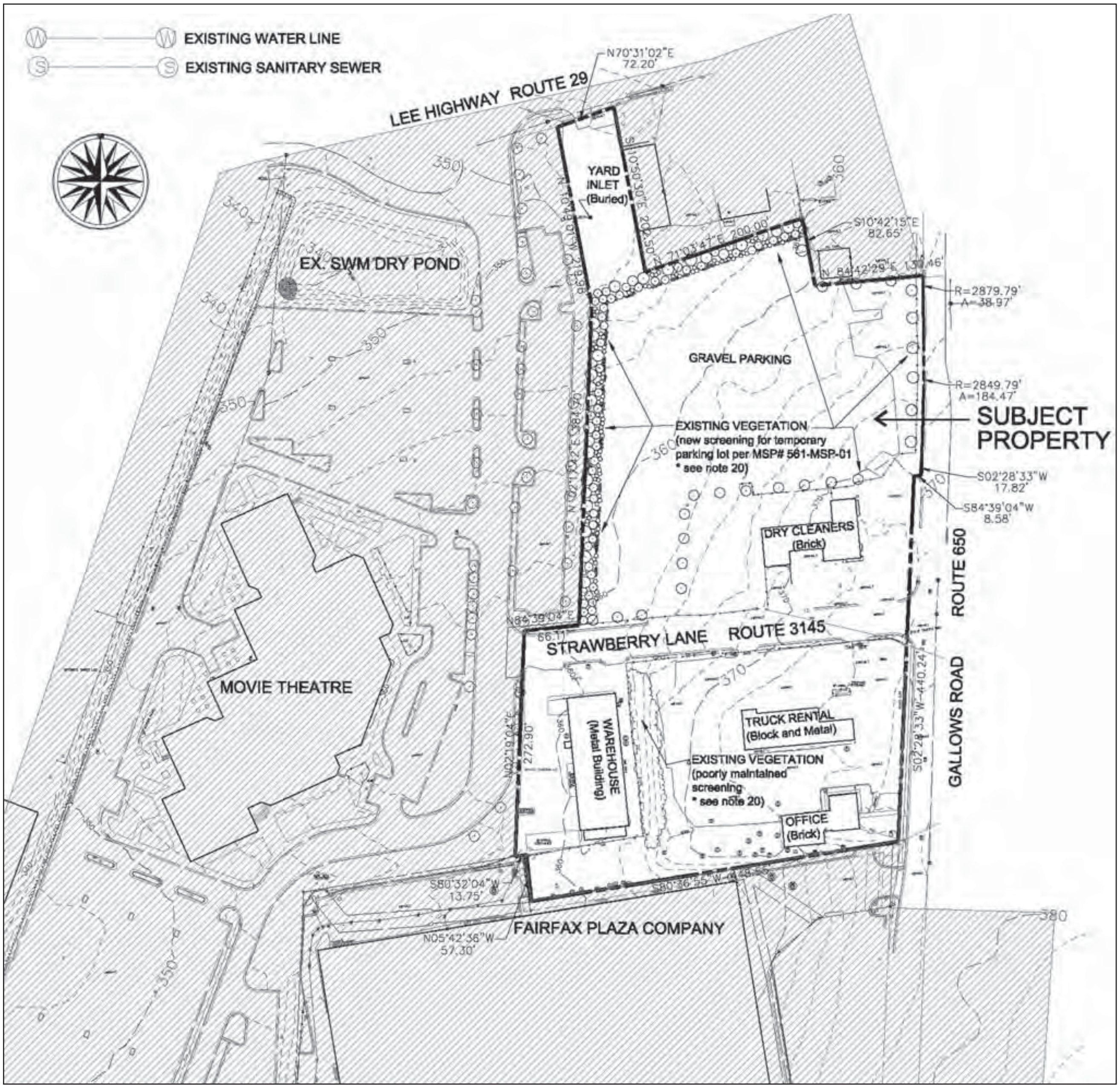


FIGURE F.2 Existing condition map and site inventory.

■ Fairfax County Division of Wastewater Planning and Monitoring confirmed capacity in adjacent sewer mains. They determined that initial load estimates would result in at least two new connections. Given the topography of the site, these taps would actually be in separate sewer sheds, one of which was subject to reimbursement fees.

■ Dry utilities including gas, electric, telephone, and fiberoptic were present in the area. Overhead utilities would need to be relocated and caution exercised to resolve proposed road and utility improvements near the existing gas and fiberoptic lines in Gallows Road.

In terms of access and circulation, the existing street system was less than desirable from both a pedestrian and a vehicle perspective. Both Gallows Road and Lee Highway, the two framing arterials, were included in the Virginia Department of Transportation (VDOT) six-year Road Improvement Plan. The massive proposed at-grade intersection and the ripple-effect improvements along each corridor would drastically affect the subject site. Additionally, the county comprehensive plan identified circulation improvements within the Town Center area to enhance connectivity between the transit station area to the north and the Town Center as well as facilitating the transformation from industrial to mixed use. (See Figure F.3.) An analysis of the site

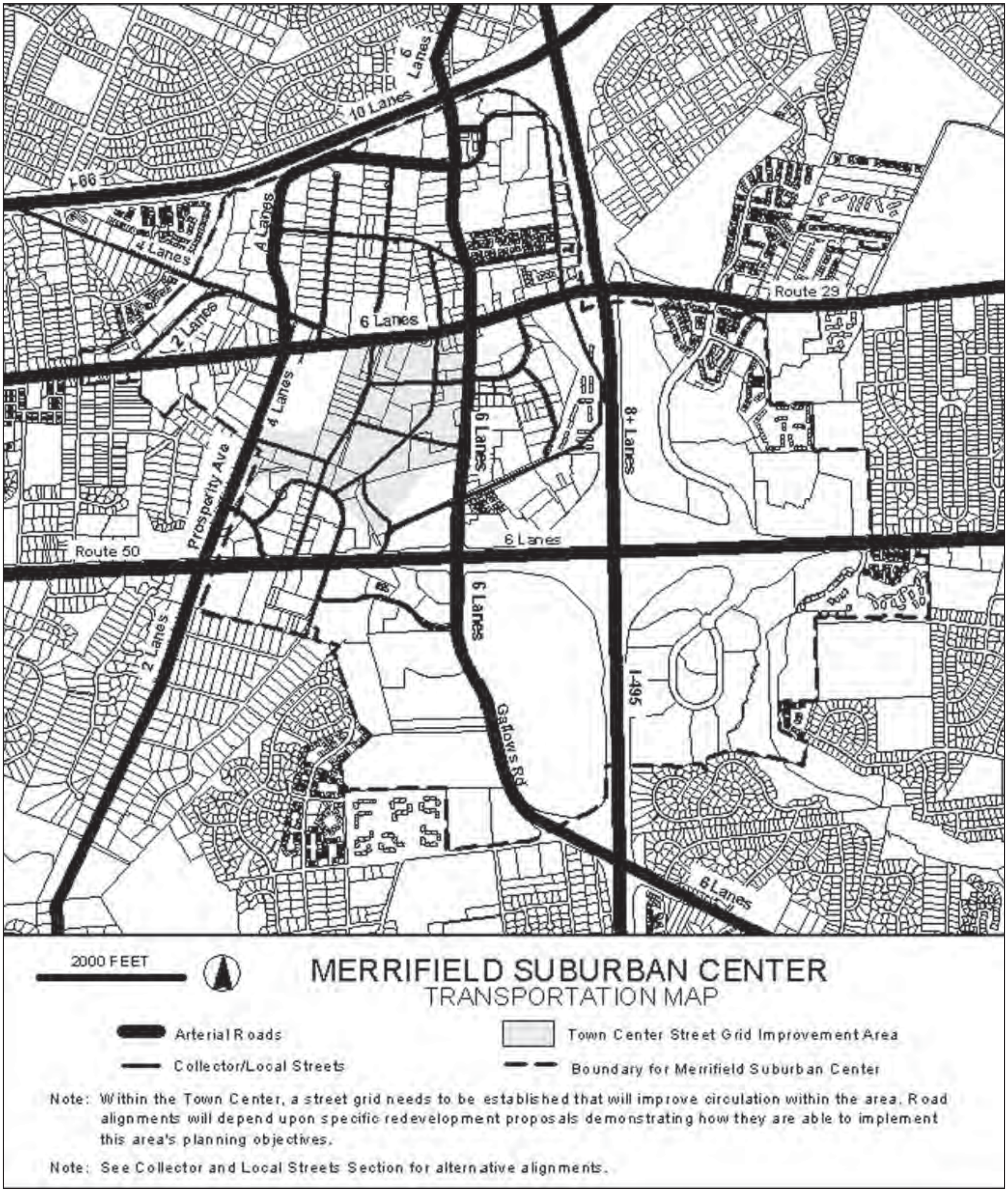


FIGURE F.3 Merrifield Suburban Center Transportation Plan.

development consequences of VDOT's and Fairfax County's complementary road improvement scenarios revealed the following key components:

- Strawberry Lane would need to be realigned and improved through the site.
- Additional right-of-way (ROW) dedication along Gallows Road would be required to accommodate VDOT's intersection improvements and street widening.
- Direct connections (entrances) to the site from Lee Highway and Gallows Road would not be possible based on proximity to the existing and proposed Lee/Gallows intersection.

The realignment of Strawberry and ROW dedications for Strawberry and Gallows would result in a substantial change in configuration of the buildable site area: conservative estimates based on early research of VDOT plans indicated a net reduction of nearly 2 acres. (See Figure F.4.) These cursory observations laid the groundwork for conceptual design efforts and prompted more detailed analysis in the form of a traffic study. A detailed traffic study was performed (by others) to quantify ROW needs for both Strawberry and Gallows and determine signalization and intersection improvements for the realigned Strawberry/Gallows/Porter intersection. The results of this study became available and were incorporated during the schematic design phase (see below for further details).

Not only did the proposed widening of Gallows affect the site buildable area, but it presented a challenge in terms of grading for pedestrian, specifically handicap, accessibility. There was over 10 feet of grade change along Strawberry Lane; with the widening of Gallows, this grade change was exacerbated. Although it was fairly clear how to fit the build-

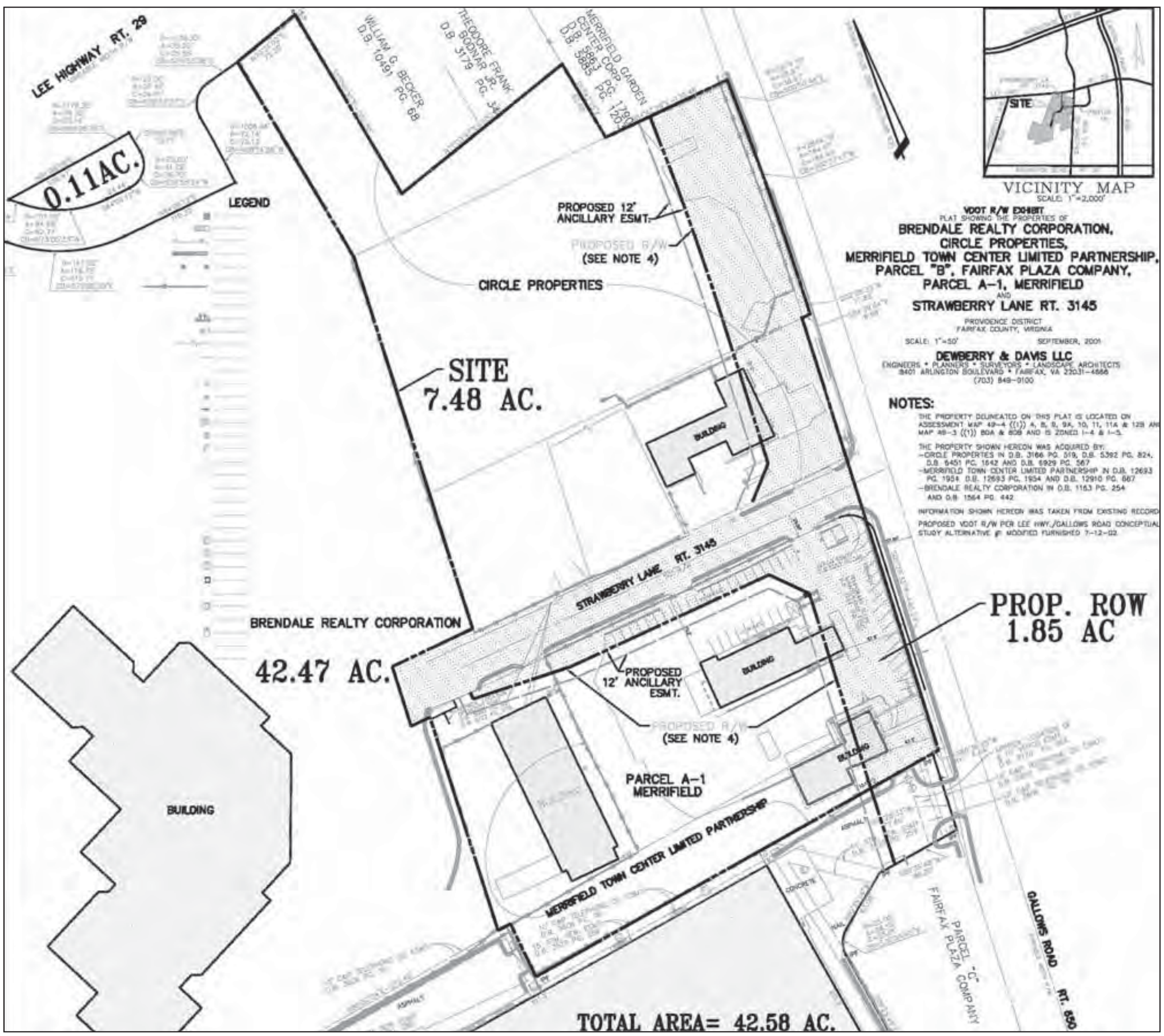


FIGURE F.4 Proposed ROW dedication as determined during the engineering feasibility analysis.

ings into the topography to take advantage of multistory retail and structured parking, designing the sidewalks and streetscape to meet handicap accessibility standards would take careful attention to detail and creative manipulation of building entry features to ensure accessible routes.

While the drastic grade change on the site presented a challenge in terms of grading for accessibility, it facilitated storm drain and stormwater management (SWM) design. Given the tight buildable area conditions, underground SWM facilities were planned even during feasibility. A clear redevelopment project quantity and quality control were required according to Fairfax County guidelines. The primary concern at this stage of the land development process was stormwater outfall adequacy. Four separate pipe outfalls were identified on the site; further investigation of the storm drainage systems revealed that all four systems rejoined downstream and ultimately discharged into an unnamed branch of Accotink Creek. Modeling the outfall systems would require additional field survey and plan research in order to piece together the outfall path to the requisite distance downstream.

Site Analysis

Comprehensive Planning and Zoning in Fairfax County. As discussed earlier in the text, concurrent with the site feasibility assessment is the site analysis—the first step of which is to evaluate the county's comprehensive plan. This step is crucial in Fairfax County since the comprehensive plan is the basis for land use decisions. Although a comprehensive plan is only a guide and not a legal document per se, it is extremely rare for a development proposal to be approved that is not in strict conformance with the comprehensive plan.

The emphasis and reliance on the comprehensive plan is a result of two noteworthy community planning efforts in Fairfax County: the 1970s Planning Land Use System (PLUS) and the 1990s Fairfax Planning Horizons process. Both efforts were initiated by the board of supervisors to improve planning, identify county goals and priorities in terms of the built environment, and facilitate responsible growth through informed community decision-making processes. County residents played a major role in each of these visioning exercises via the creation of task forces, surveys, and countless public meetings. Ultimately, the Horizons process replaced the 1975 PLUS plan with:

- An updated policy plan that describes jurisdiction-wide policies relating to land use, transportation, environment, public facilities, and housing
- Revised area plans that provide planning district and community planning sector recommendations on a parcel-specific level
- Comprehensive plan and transportation plan maps

The Horizons process utilized the Concept for Future Development (1990), comprising the Concept Map, the Land Use Classification System, and the Land Use Classification System Guidelines, to modify the area plans. The Horizons process represents the last significant effort by Fairfax County to revise the comprehensive plan; upon adoption of the Horizon plan, the regularly scheduled annual plan review process, a four-year cycle, commenced.

County growth areas were further defined in the Horizons plan through the identification of localized mixed-use centers and industrial/institutional centers in the Concept for Future Development and carried out in the area plans. Despite several plan revisions during the early 1990s, the Greater Merrifield Business Association and several other local citizen groups felt the comprehensive plan language for the Merrifield Suburban Center still reflected recommendations from the 1970s and '80s. This community coalition pushed for a visioning workshop to address the future redevelopment of the area. As a result of this collaborative effort between the community and the county, the plan language was enhanced in 2001 to provide for a more urban core, mixed-use in nature, and connected via green space and pedestrian ways to the transit station area. This designation in the comprehensive plan served as the foundation for the Town Center development, laid the groundwork for subsequent rezoning and design efforts, and engaged this already active community in the future redevelopment process. (See Figure F.5.)

The property is located in Area I in the Merrifield Suburban Center, specifically Land Unit F, Sub-unit F1, as shown in Figure F.6. The comprehensive plan text for the Merrifield Suburban Center is twofold: *areawide recommendations,* which identify the overall vision and framework for development in the center (i.e., the urban design concept), and *land unit recommendations,* which specify planned use and intensity for each unit and subunit.

Merrifield Suburban Center Areawide Recommendations—Urban Design. First and foremost, the property was identified as a component of the Town Center *core area.* The applicable *land use* recommendation for core areas stated:

> The highest development intensities and the most "urban" areas of the Merrifield Suburban Center will be located within the designated core areas: the "Town Center Area" and the "Transit Station Area." Within these areas, mixed-use development is encouraged and may include office, residential, retail, hotel, major entertainment uses, as well as institutional, cultural, recreational, and governmental uses. To encourage a more urban environment, new buildings should be located close to roadways while allowing for streetscape amenities such as street trees, sidewalks, plazas, street furniture, and landscaping. Locating buildings closer to the roadway means that most off-street parking will be located in structures behind or beneath buildings. Parking structures should generally be integrated with an associated building in a manner that maximizes usable open space and the provision of pedestrian linkages.[1]

[1]Fairfax County. *Fairfax County Comprehensive Plan,* 1975 as amended through July 2003.

CONCEPT MAP FOR FUTURE DEVELOPMENT

CONCEPT MAP FOR FUTURE DEVELOPMENT

LOCATIONS OF MIXED-USE CENTERS

Urban Center
1. Tysons Corner Urban Center

Suburban Centers
2. Fairfax Center
3. Dulles (Route 28 Corridor)
4. Reston-Herndon
5. Merrifield
6. Flint Hill
7. Centreville
8. Lorton-South Route 1

Community Business Centers
9. McLean
10. Seven Corners
11. Baileys Crossroads
12. Annandale
13. Springfield (West)
14. Kingstowne
15. North Gateway and Penn Daw
16. Beacon/Groveton
17. Hybla Valley/Gum Springs
18. South County Center
19. Woodlawn

Transit Station Areas
20. Huntington Metro Station
21. Van Dorn Metro Station
22. Franconia/Springfield Metro Station
23. West Falls Church Metro Station
24. Dunn Loring Metro Station
25. Vienna Metro Station

LOCATIONS OF LARGE INSTITUTIONAL AND INDUSTRIAL AREAS

Industrial Areas
26. Beltway South
27. Ravensworth
28. I-95 Corridor

Large Institutional Land Areas
29. Washington Dulles International Airport
30. George Mason University
31. Fort Belvoir (Main Post and Engineer Proving Ground

LEGEND

Suburban Neighborhoods (Residential density ranges defined in Area Plans; 0.15-0.25 FAR* for neighborhood-serving non-residential use)

Low Density Residential Areas (Residential density of 0.1 to 0.5 du/ac **, specific density ranges in Area Plan; Non-residential use intensity 0.05 to 0.1 FAR)

Tysons Corner Urban Center
Core (1.0-1.65 FAR; 35-60 du/ac)
Non-Core (0.25-1.0 FAR; 8-45 du/ac)

Suburban Centers
Core (0.3-0.8 FAR; 15-35 du/ac)
Non-Core (0.15-0.30 FAR; 5-25 du/ac)

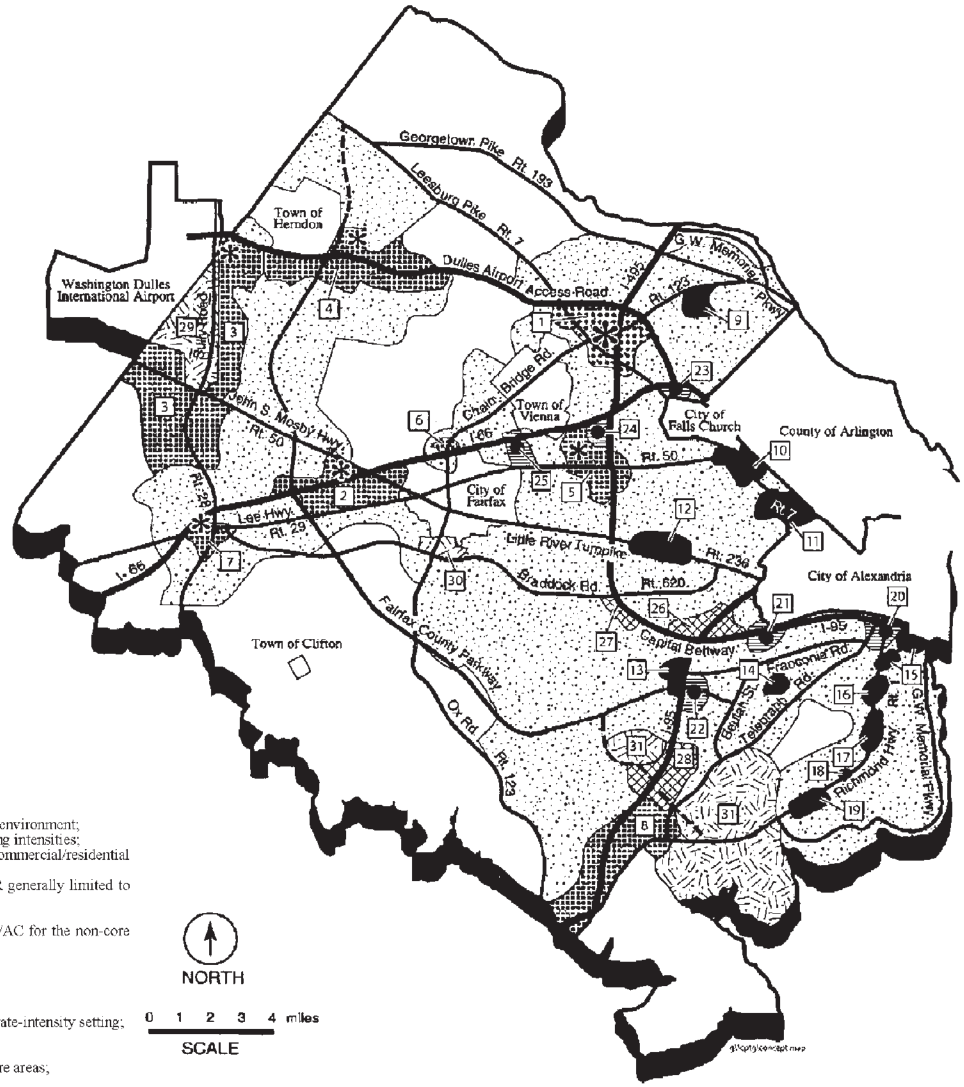
Community Business Centers (0.20-0.50 FAR; 5-25 du/ac; if a core is designated, intensities of up to 0.70 FAR may be allowed)

Transit Station Areas (0.30-1.00 FAR; 8-45 du/ac)

Industrial Areas (0.25-0.50 FAR for Industrial Uses)

Large Institutional Land Areas

* FAR - floor area ratio
** du/ac - dwelling units per acre



Tysons Corner Urban Center:

- contains a mixture of high intensity office, retail, and residential uses in a pedestrian-oriented, urban environment;
- consists of one or more core areas of highest intensity uses and peripheral areas of somewhat lessening intensities;
- has potential intensity for a core of 0.50 to 1.5 FAR, with intensities above 1.0 FAR limited to commercial/residential mixed-use projects;
- has potential intensities of 0.25 to 1.0 FAR in the non-core areas (with intensities above 0.70 FAR generally limited to commercial/residential mixed use projects);
- areas adjacent to single-family neighborhoods should be generally from 0.25 to 0.50 FAR;
- has potential residential densities of 35 to 60 DU/AC for a core area and densities of 8 to 45 DU/AC for the non-core areas (areas adjacent to single-family neighborhoods should be generally from 8 to 25 DU/AC);
- requires TSM programs which encourage the use of transit, carpools, and vanpools;
- makes planning provisions for transit alternatives.

Suburban Centers:

- encourage a complementary mixture of office, retail, and residential uses in a cohesive, low to moderate-intensity setting;
- contain core areas with a relatively greater intensity and more urban characteristics;
- have potential intensities of 0.30 to 0.80 FAR for cores and 0.15 to 0.30 FAR for non-core areas;
- have potential residential density ranges of 15 to 35 DU/AC for cores and 5 to 25 DU/AC for non-core areas;
- employ TSM programs to minimize traffic congestion.

FIGURE F.5 Concept map for future development.

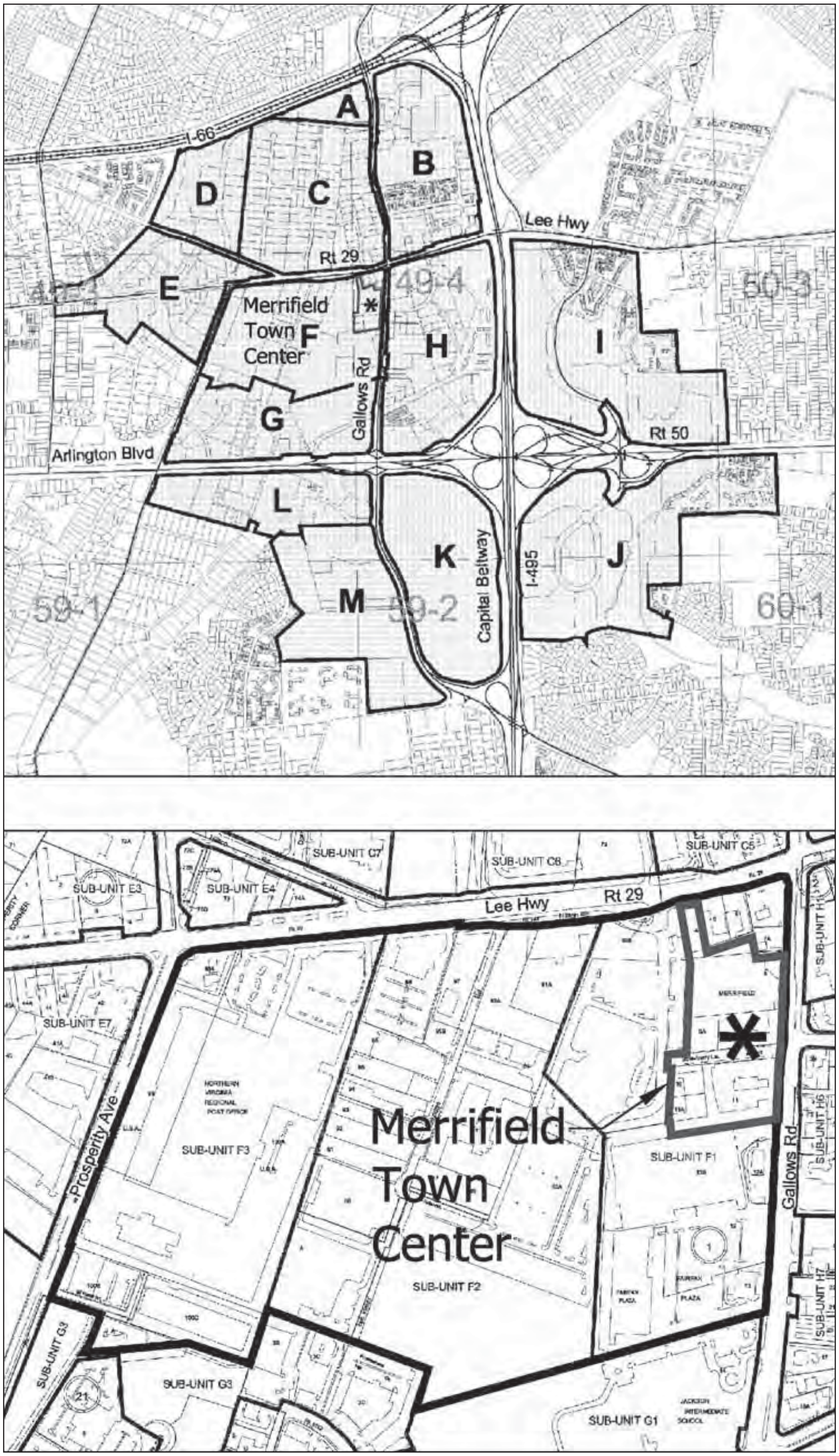


FIGURE F.6 Merrifield Suburban Center/Merrifield Land Unit F-1.

To encourage utilization of the mixed-use designation, additional land use requirements such as the inclusion of ADUs as well as parcel consolidation and/or coordinated development plans are also noted. The provision of ADUs in a development program yields density bonuses necessary to achieve the high end of the allowable intensities specified, while consolidation/coordination ensures proper integration of the project into the changing community.

In addition to the land use recommendations, the areawide recommendations outline the specific *urban design* components of redevelopment efforts in the center, particularly in the core areas. The primary urban design goals for the Town Center are to create a sense of place and encourage alternative transportation modes through provision of:

- Attractive, landscaped, pedestrian-friendly streets
- Buildings with a distinctive architectural character and street presence
- High-quality design in terms of integrated and coordinated building design and materials, open-space amenities, and recreational space

To achieve these goals, the MTC plan would need to exemplify improved connectivity and quality of spaces. The primary means of physically achieving the goal is through the streetscape design. The plan identifies four typical streetscape sections, two of which would be component parts of the MTC plan: the *boulevard* street, applied to both Lee Highway (Rt. 29) and Gallows Road, and the *cross* street, applicable to Strawberry Lane. (See Figure F.7.)

The other two components of the areawide recommendations are *transportation* and *public facilities/infrastructure*. These portions of the recommendations are intended to be synergistic with the urban design recommendations. By improving or ensuring the adequacy of the public infrastructure and facilities serving the development, the overall experience for residents of and visitors to the Merrifield Suburban Center is enhanced and a variety of transportation modes become equivalent options. As previously noted in the "Feasibility" section, primary transportation improvements directly tied to redevelopment of the MTC site involved the proposed intersection at Lee and Gallows, the widening of both of these arterials to six-lane roads, and the improvement of Strawberry Lane (realigned with Porter Road). Other noteworthy transportation improvements proximal to the site that would ultimately bear weight in terms of the rezoning effort and proffer development included required improvements to Eskridge Road, Transportation Demand Management (TDM) implementation requirements, and policies pertaining to ROW acquisition, mitigation of transportation impacts, site access points, parking area access and location, and funding of transportation improvements and services.

Because the site is located in a largely developed portion of Fairfax County, the bulk of the public facilities and infrastructure—fire and police stations, libraries, schools, and utilities—was already in place and required little improvement or small additions. Components identified as lacking within the comprehensive plan included open space, recreational, and stormwater management facilities, all of which required closer attention and consideration during redevelopment to address existing deficiencies and/or downstream problems.

Each of the four components of the areawide recommendations—land use, urban design, transportation, and public facilities/infrastructure—would need to be addressed and integrated into the rezoning documents in order to receive a favorable opinion during the public review process.

Merrifield Suburban Center Land Unit Recommendations—Program. Land Unit F is envisioned as the Town Center portion of the Suburban Center. Sub-Unit F1 presents the base plan for the subject site as well as two options for redevelopment that would provide greater density within the context of the Town Center urban design concept. (See Figure F.8.)

The base plan for Sub-Unit F1 was "community-serving retail up to 0.35 FAR" with a possible office component. Options 1 and 2 allowed an increase in density to 0.65 FAR for office and retail uses or 1.2 FAR for mixed-use including a residential component. To encourage pursuit of these redevelopment options, height and density bonuses are provided for such things as provision of ADUs and underground parking as outlined in the comprehensive plan and zoning ordinance.

Conclusion to Feasibility and Site Analysis of Merrifield Town Center

The end result of the first steps of the land development process was a go decision on the part of the client. All the pieces were in place—a prime location, site conditions that could be overcome and improved, and promising, enabling comprehensive plan language that was supported by the local community. Following the go decision, the process truly took flight as rezoning efforts and more detailed engineering analysis commenced to refine the development program and bring Uniwest's vision to life.

An important aspect of the comprehensive planning and zoning process is a basic awareness of how the local government operates in accordance with its jurisdiction size, structure of government, legislative authority granted by the state, and the degree of participation by the residents of the community. In order to understand the land development process as it relates to Merrifield Town Center, it is important to become familiar with the basic structure of the Fairfax County government and the participants in the process.

The governing body in Fairfax County is the board of supervisors. The citizens elect one supervisor from each of the nine districts and an at-large chairperson every four years. The board of supervisors plays a major role in the land development process: they formulate and adopt ordinances and policies relating to the development process as well as review and approve rezoning, special-exception applica-

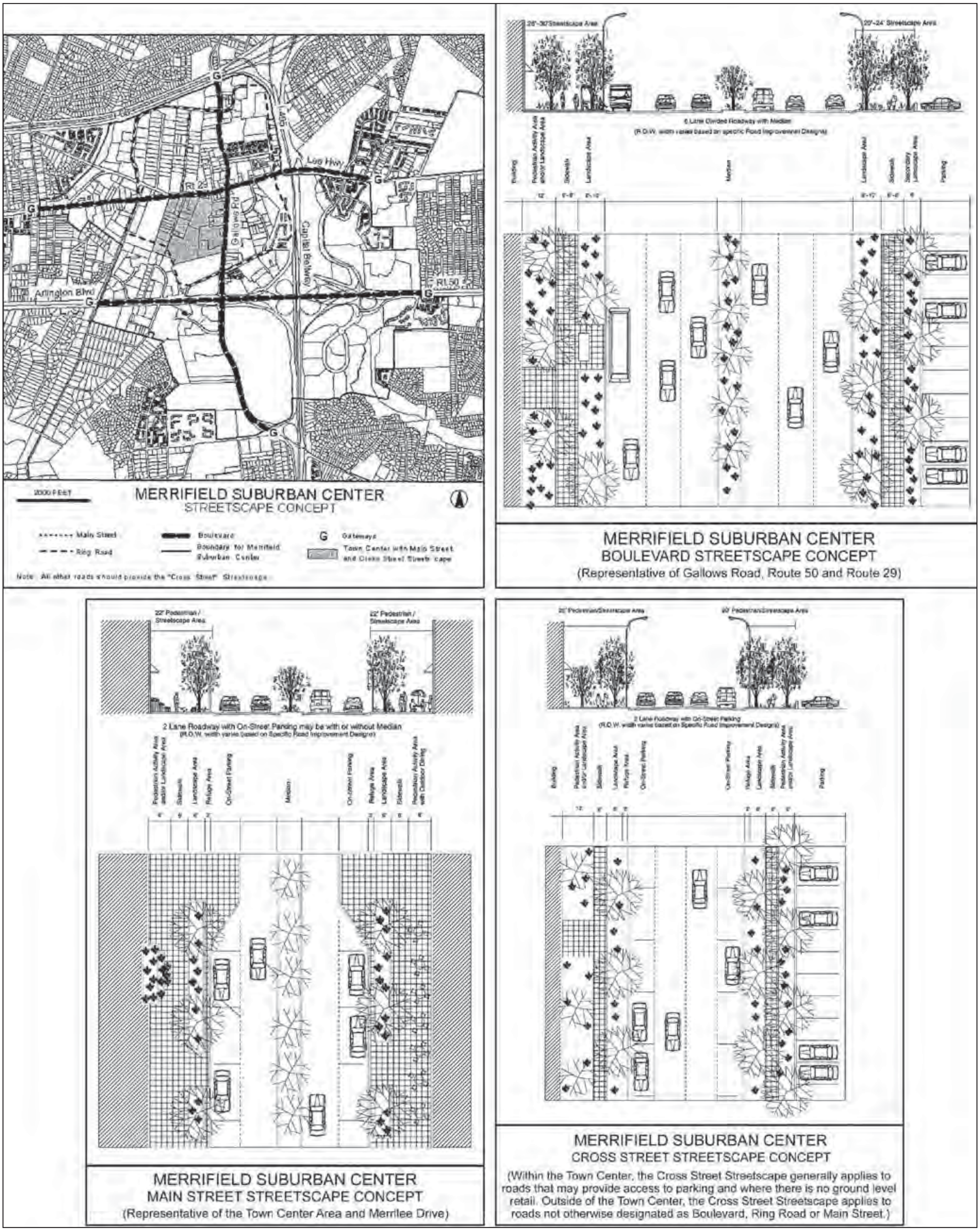
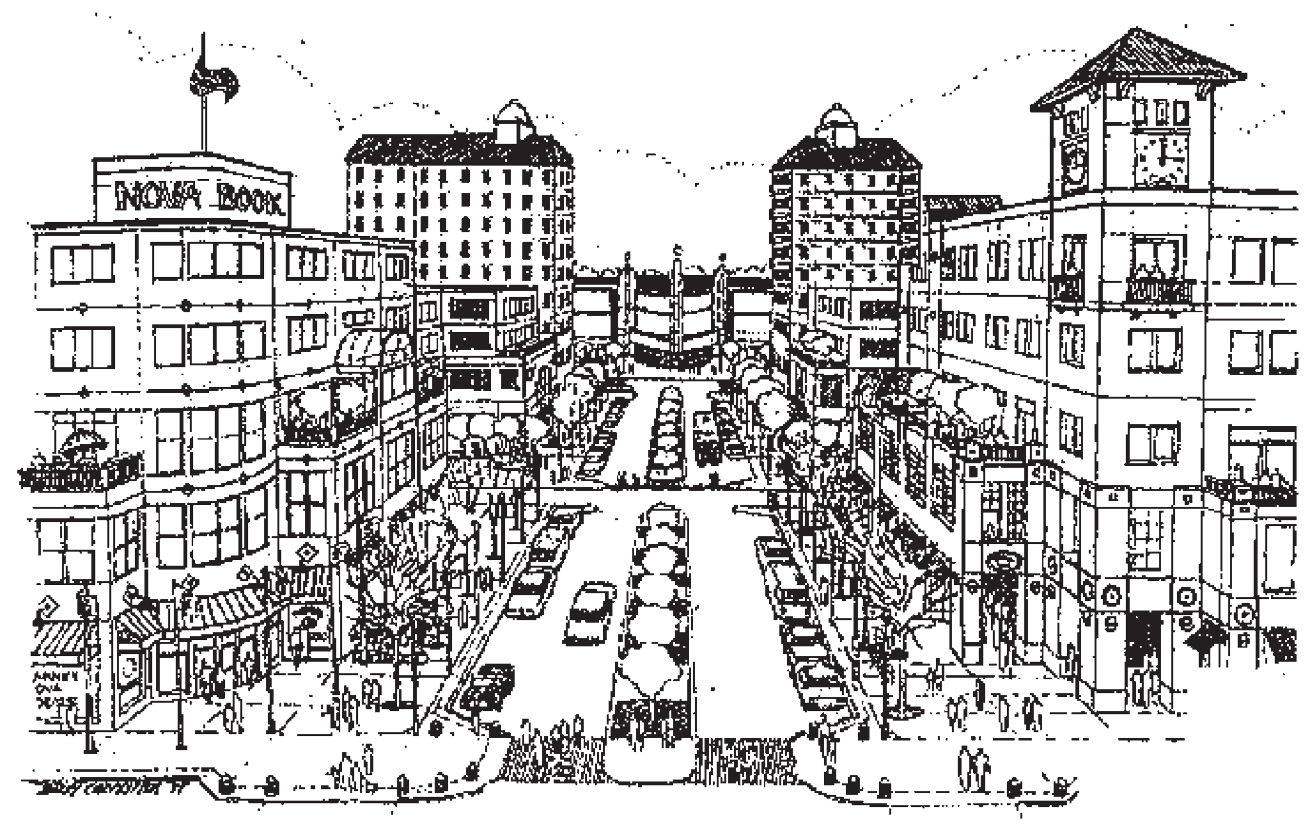


FIGURE F.7 MTC streetscape typical sections identified in the comprehensive plan.



EXAMPLE OF POTENTIAL TOWN CENTER DEVELOPMENT

Note: This figure is intended to be illustrative only. Building heights within the Town Center should vary with maximum building heights being up to 115 feet (9 stories), as indicated in the sub-unit recommendation.

FIGURE F.8 Town Center urban design concept as identified in Fairfax County comprehensive plan.

tions, and amendments to the comprehensive plan. The board of supervisors delegates the bulk of the land use coordination and negotiations to the planning commission. The planning commission is a 12-member body appointed by the board of supervisors. Each supervisor appoints a member to represent his or her district for a four-year term and the chairman of the board appoints three at-large members. Generally, the planning commission holds public hearings twice a week. The board of supervisors makes the final decision on the majority of land use matters and, historically, board members rely heavily on planning commission recommendations. Although there have been rezoning cases in which the board of supervisors has overruled a planning commission recommendation, it is atypical of the process.

As a result of the increased sophistication of the citizens and their influence in the land development process in Fairfax County, organizations made up of representatives of various homeowners associations have been formed within individual supervisor districts to advise the planning commission and board of supervisors on land use matters. For example, the Greater Merrifield Business Association (GMBA) is a nonprofit organization established in 1984. This group advised the planning commission and board of supervisors during the planning process of Merrifield Town Center. These types of citizen organizations have become very influential in the land development process; many supervisors and planning commission members strongly suggest that applicants present their proposals to these groups prior to the planning commission public hearing. It is difficult to receive a favorable recommendation from the planning commission or board of supervisors without the support of local citizen groups. It is not uncommon for the design team to meet with these local citizen/business groups several times prior to public hearings in order to adequately address their concerns.

In addition to the political decision makers, there are usually homeowners in proximity to the proposed development who have concerns or self-serving interests regarding the proposal. Sometimes, these citizens are not part of a homeowners association and lack representation within one of the larger community citizen organizations. The members of the planning commission and board of supervisors rely heavily on input from the adjacent homeowners of a given project, and their concerns must also be addressed along with those of the larger citizen organizations.

PART III: CONCEPTUAL DESIGN

Based on the preliminary investigations and Uniwest's economic assessments of the possible development scenarios, the decision was made to pursue the mixed-use option (option 2) identified in the comprehensive plan. In 2003, when the land development process was initiated, the housing market was exploding in the Washington, D.C., metro area; market demand paired with a desirable location and a firm assurance from Dewberry that the program could be delivered within the confines of the jurisdictional requirements allowed Uniwest to move forward in the development process with confidence. In order to achieve the desired program, rezoning would be required, thus exposing the client and their program to the public review process. Prior to initiating the formal rezoning process, conceptual and schematic-level designs were completed to thoroughly investigate design options and ensure that the development program put forward in the public process would comply with relevant standards and sit favorably with the community and the political leaders.

Development Patterns and Principles

Given the program, site size (not even 7.5 acres), and configuration (nearly rectangular but bisected at a severe angle by Strawberry Lane), both horizontal and stacked mixed-use development scenarios were investigated. With only conservative estimates of the ROW requirements for improved Strawberry Lane and Gallows Road, the buildable area of the site was somewhat in flux, although it was clear there would be two distinct land bays, the primary corners of which posed an intriguing design dilemma, given their geometry. Programming discussions during the feasibility step revealed that nearby Reston Town Center was a desirable model to emulate in terms of overall aesthetics and sense of place. Using Reston as a guideline and to optimize the building program, stacked mixed-use emerged as the most practical arrangement of space. As in most stacked mixed-use scenarios, it was determined that both land bays would support ground-level retail with a residential tower above.

Overall massing of the buildings and orientation of the residential component were critical in terms of design development. Once the decision to pursue mixed-use programming was made, initial floor area computations were completed in order to begin determining building massing arrangements. With two large land bays, massing seemed self-evident; however, the substantial ROW dedications, combined with previously identified comprehensive plan recommendations to enhance/provide open space and recreational facilities with any residential components, created additional context for design. Several alternatives were examined to achieve the client's desired density while building in valuable open space. From pocket parks and streetscaping to greenroofs, nearly every open-space option was investigated in terms of added amenity value, cost, and construction feasibility. Ultimately, it was determined that a sizeable park, one that provides amenities beyond the small oasis of a pocket park, would likely be required given that three plazas/urban greens were identified in close proximity to the site on the Merrifield Suburban Center Open Space and Pedestrian System Map.

With open-space and ROW requirements tentatively delineated, general building footprints were developed for each land bay, taking into account the unique corner treatments that would be required in order to accommodate the alternating acute and obtuse angles formed at the primary entrances to the site along improved Strawberry. In addition to the urban park and required streetscaping, several possible pocket parks were identified as options in the "leftover" corner areas. Desirable views for the residences were identified: improved Gallows and Lee Highway would be active, streetscaped boulevards, although traffic heavy (noisy); Strawberry Lane would be the eastern entry to the town center; and west of the site would be future phases of the Town Center likely similar in architecture and programming. Based on these considerations as well as architectural concerns related to depth and structural systems, U-shaped towers were devised on each building to take advantage of the prime frontage on improved Gallows and Strawberry as well as the Town Center expansion.

In addition to the buildings themselves, access considerations—vehicular and pedestrian—continued to affect design development. From the feasibility investigation, it was determined that vehicle access from Gallows and Lee Highway would be restricted; in fact, no new entrances would be permitted, leaving Strawberry as the primary entry and access to the site. The grade change along Strawberry was ideal in terms of providing direct access to various levels of structured parking; however, the location of multiple such entrances along Strawberry would have substantially disrupted the required streetscape, pedestrian experience, and desirable retail street presence. The street just west of the site was private south of Hilltop Road and as such would require permission from the neighbor, easements, and/or access rights in order to devise usable entries to the site. The design team deemed this approach questionable at best, given the various states of redevelopment of the neighbors and the need to access both the north and south land bay. Once the obvious access solutions were exhausted, the design team began to consider an alternate approach in the form of a private service drive. Although this arrangement resulted in additional roadway infrastructure and less buildable area, it successfully kept moving and delivery vehicles out of the main Town Center entry street, provided for park maintenance access, and allowed private access for both buildings, giving residents and commercial users a sense of privacy and exclusivity. (See Figure F.9 *a–c*)

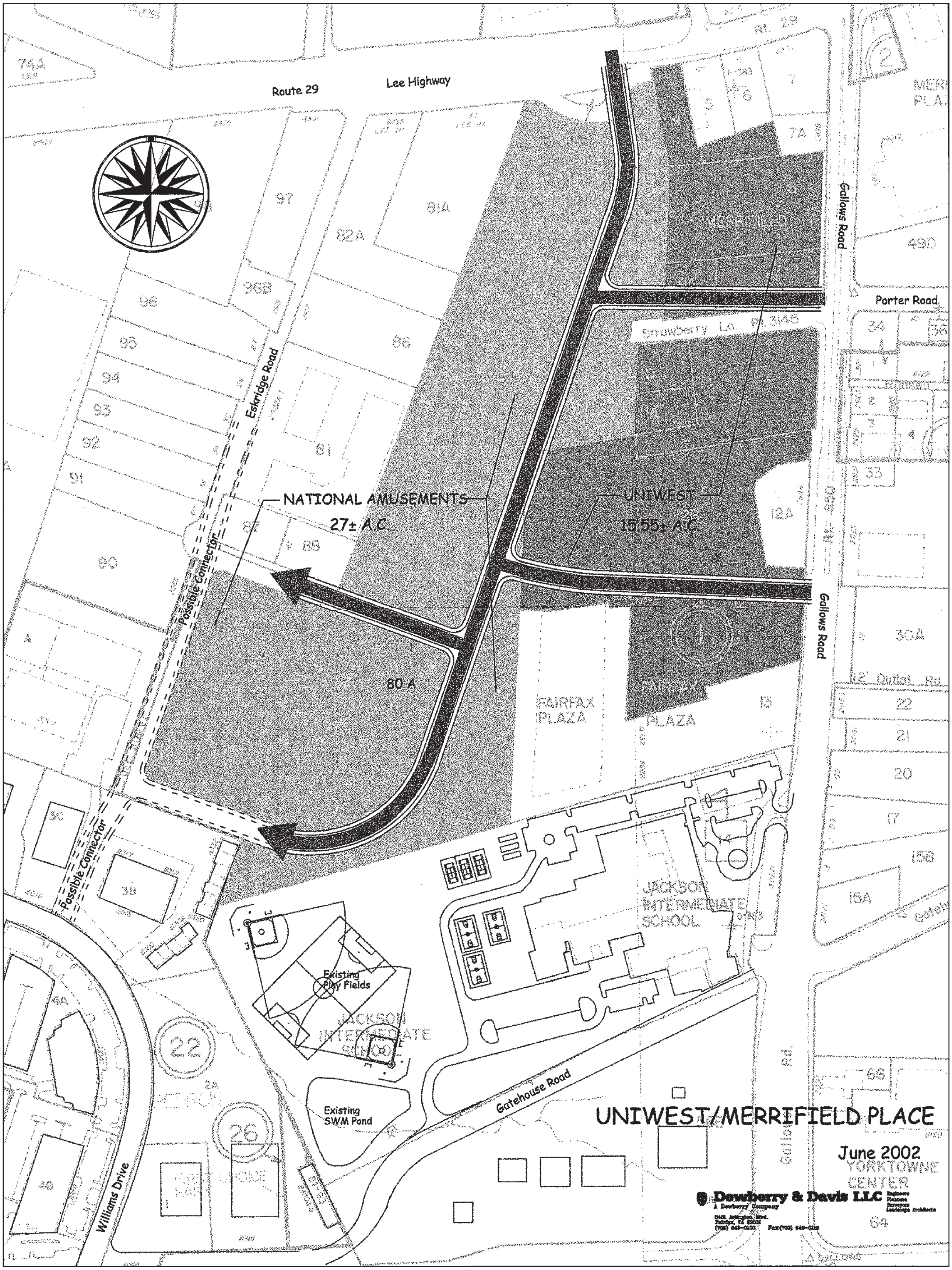


Figure F.9a Merrifield Town Center conceptual design: site concept.

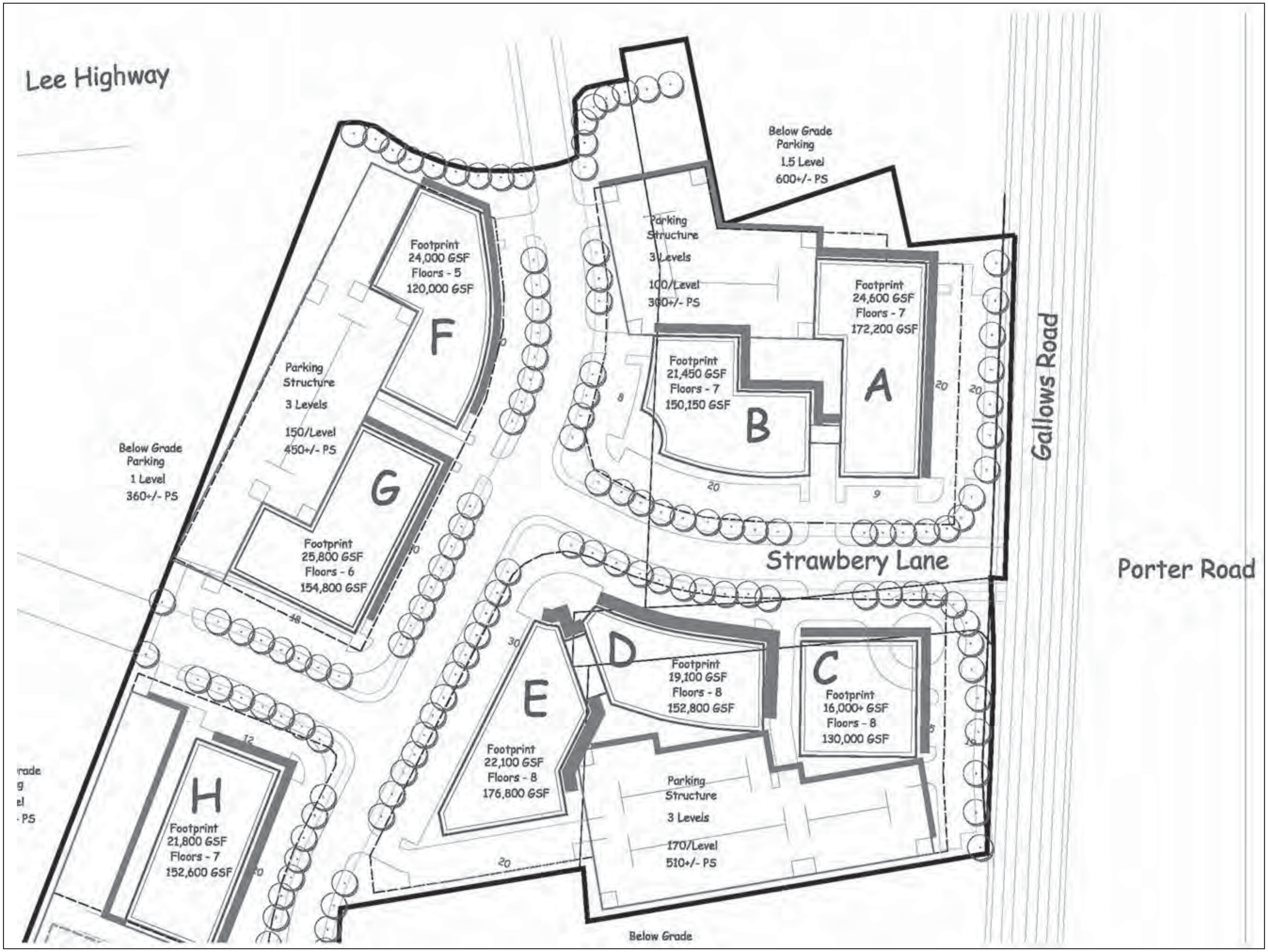


FIGURE F.9B Merrifield Town Center conceptual design: site concept.

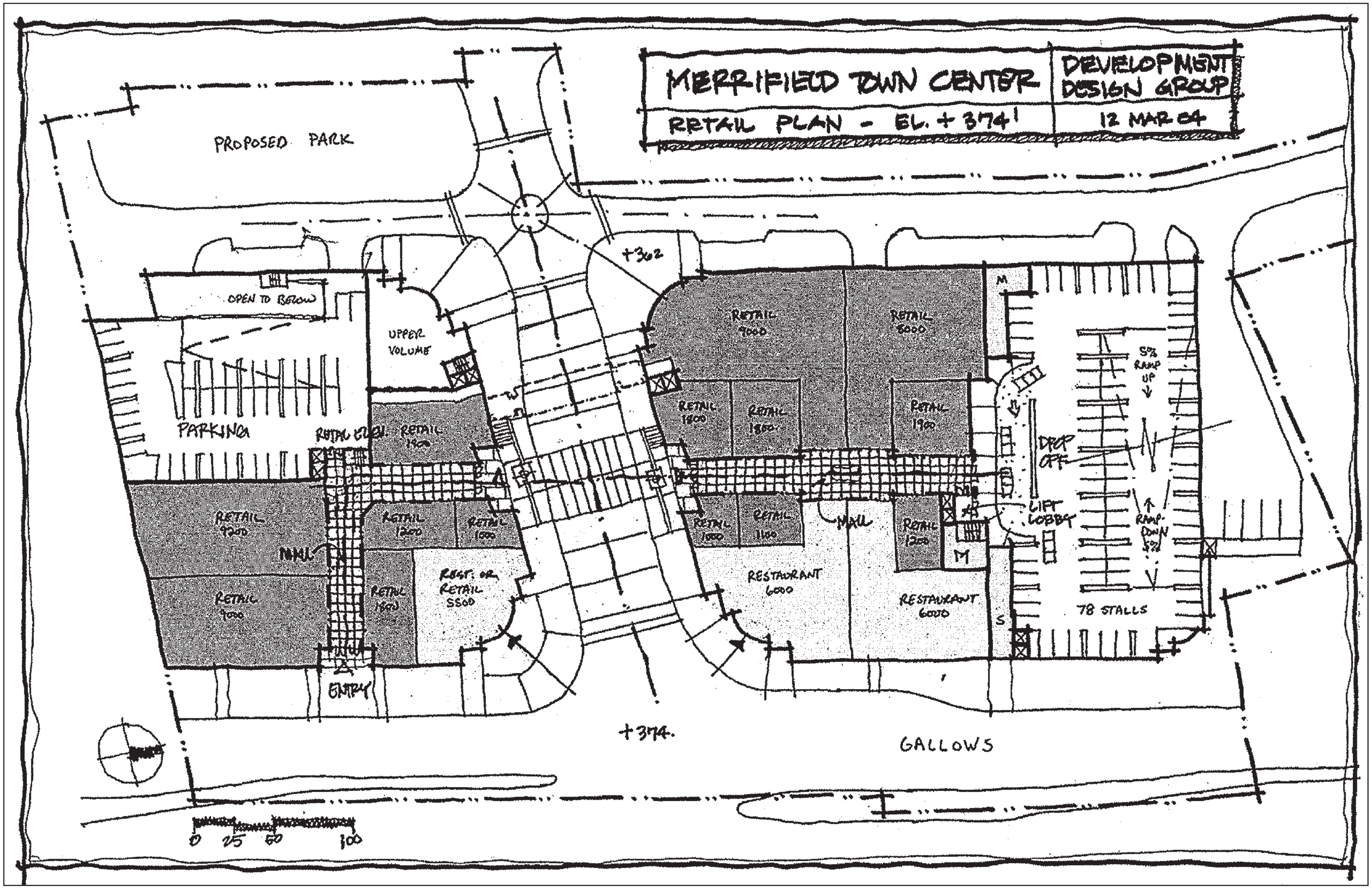


FIGURE F.9c Merrifield Town Center conceptual design: internal building concept prepared by the Development Design Group to facilitate site/building coordination during final design. (Reprinted with permission of Development Design Group, Inc.)

PART IV: SCHEMATIC DESIGN

To refine the general site layout developed during conceptual design, the land development consulting team systematically quantified the public infrastructure improvements—specifically the public road and open-space requirements. First, the results and recommendations from completed specialty studies—traffic, community impact, and geotechnical—were combined with the concept study to produce schematic-level drawings suitable for use as points of discussion and negotiation with local review staff, political leaders, and community members. Second, schematic design iterations were performed in response to these various stakeholder meetings in an effort to build design consensus among the client, design team, neighbors, and jurisdictional entities prior to and during the formal rezoning effort.

Preliminary Engineering and Design

On-site infrastructure improvements resolved in further detail during schematic design included over 1000 structured parking spaces, the public and private road network, pedestrian bridge location, paved loading docks, sidewalks, utility systems, grading and drainage, storm water management systems (both quantity and quality control), lighting, landscaping, and recreational open space. Each of these features was engineered to a point where constructibility could be ensured pending final design. In some cases, multiple design iterations were warranted to ensure that the proposed development program met the merits of the comprehensive plan and jurisdiction guidelines. Specific sticking points during the course of redevelopment included proposed density, the required road improvements, and stormwater management.

Density. In order to pursue a mixed-use scenario on-site, meet the profitable yield level, and provide the identified infrastructure improvements, Uniwest needed to achieve maximum permissible density thresholds on the site. This could be accomplished only through provision of ADUs. Further, advanced density credit for all ROW dedications needed to be ensured in order to optimize the building program within the reduced site area. Throughout the preliminary engineering and rezoning effort, Uniwest and Dewberry planners, in conjunction with county staff (DPZ) and the district supervisor's office, examined numerous ratios of ADUs to market-rate units. Discussions focused on the appropriate mix of housing and retail for the site as well as the Town Center as a whole, since this was the first wave of redevelopment in the area.

Project Phasing. Since MTC was the first site to redevelop in the core area, phased construction, particularly required road improvements, would be necessary. Parcels north, south, and west of the site that were farther from redevelopment and not consolidated into the subject plan stood as roadblocks to completing ultimate road improvements. In addition to the unknown redevelopment time frame for neighboring properties, it came to light that VDOT's improvement schedule for Gallows Road and Lee Highway did not coincide with the MTC development schedule, resulting in a projected gap between the two projects of nearly two years. Preliminary engineering efforts focused on the identification of interim and ultimate road improvement scenarios to facilitate a smooth merger of the new development into both the existing community and the future Town Center. Careful attention to transitions at the perimeter was also a priority to ensure that grading and pedestrian facilities would tie out effectively in interim and ultimate scenarios with minimal rebuilding. Building corners and streetscape elements, particularly landscaping, were reviewed in terms of both interim and ultimate condition sight distance constraints. (See Figure F.10*a* and *b*.)

Alternate Street Designs. While it was clear that road improvements would be required as a proffered condition of rezoning, the extent, or reasonable proportion, of the required improvements assigned to Uniwest was determined through an iterative process with VDOT, FCDOT, and DPZ. The challenge throughout was reconciling the comprehensive plan streetscape recommendations, the recommendations of the traffic study, and VDOT public street standards to develop essentially two road improvement plans—interim and ultimate.

Existing deficiencies noted in the comprehensive plan (namely, the number and location of access points and the lack of adequate pedestrian and/or bicycle facilities), in addition to the traffic projections for the site, resulted in elevated concerns regarding the safety and efficiency of both vehicle and pedestrian movements through and around the site. Further, VDOT road improvement plans for Gallows Road and Lee Highway were still in preliminary stages and did not fully account for access needs such as turn lanes for undeveloped properties. Table F.1 summarizes the various road configuration recommendations and the resultant schematic designs produced.

Gallows Road. Rarely does the biggest site asset also turn out to be the biggest detriment to development. Such was the case with Gallows Road. The proposed improvements would clearly improve vehicle capacity, traffic flow, pedestrian facilities, and the aesthetics of the street; however, accomplishing these improved conditions required a substantial dedication of land and resources by Uniwest. Due to the relatively urban nature of the site and significant overhead (aerial) utilities on the east side of Gallows, the widening was proposed entirely on the western side (project side) of the street in order to avoid costly utility relocation fees and take advantage of those properties slated to redevelop, as opposed to distributing the additional ROW needs equally on both sides of existing Gallows. It was also determined that the existing lanes on Gallows were substandard in width; thus, even interim improvements would need to progress the street design in terms of compliance with public street standards. Lane and median widths would become a key point of negotiation with jurisdiction staff, as ulti-

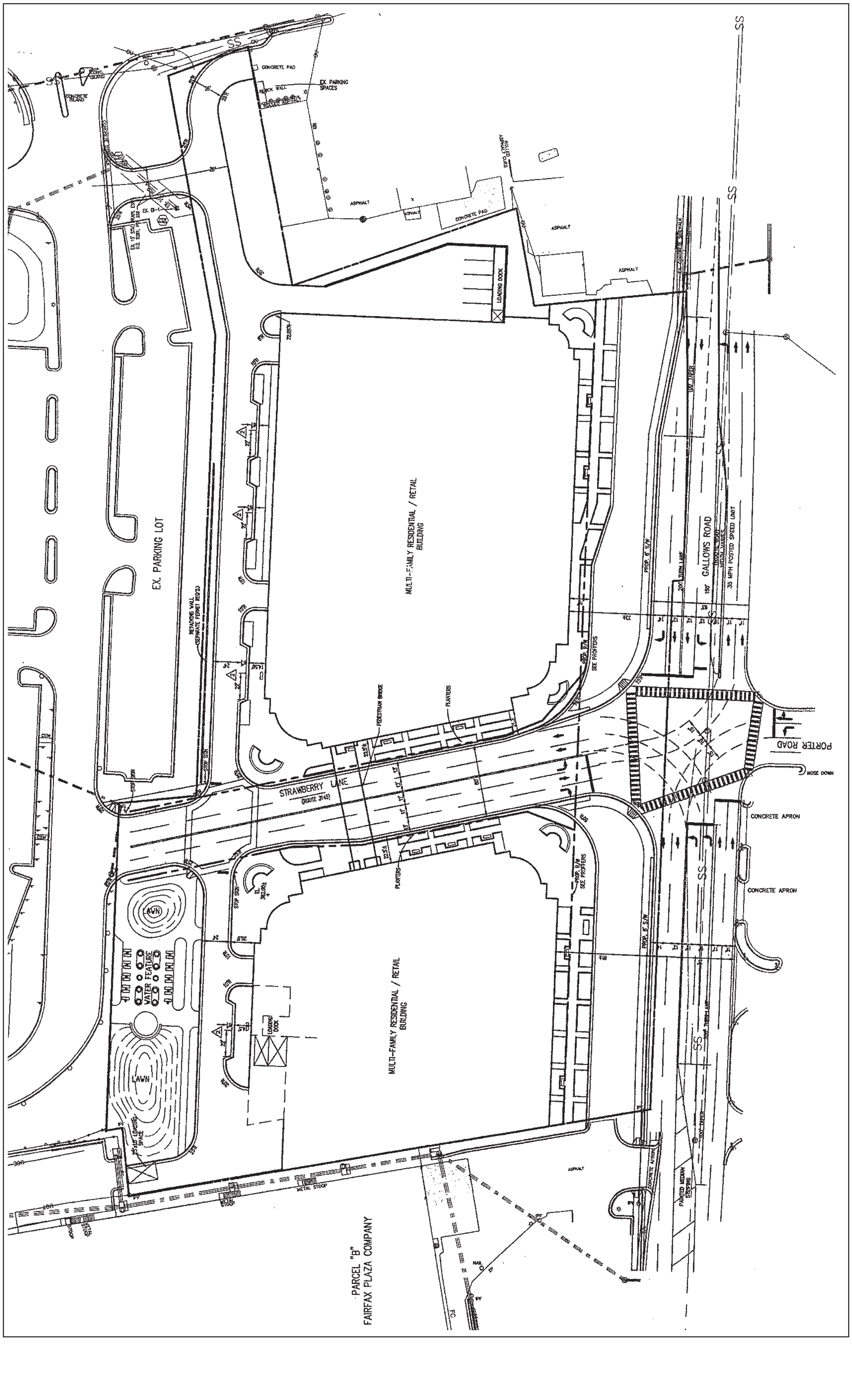


Figure F.10A Interim Gallows Road improvements.

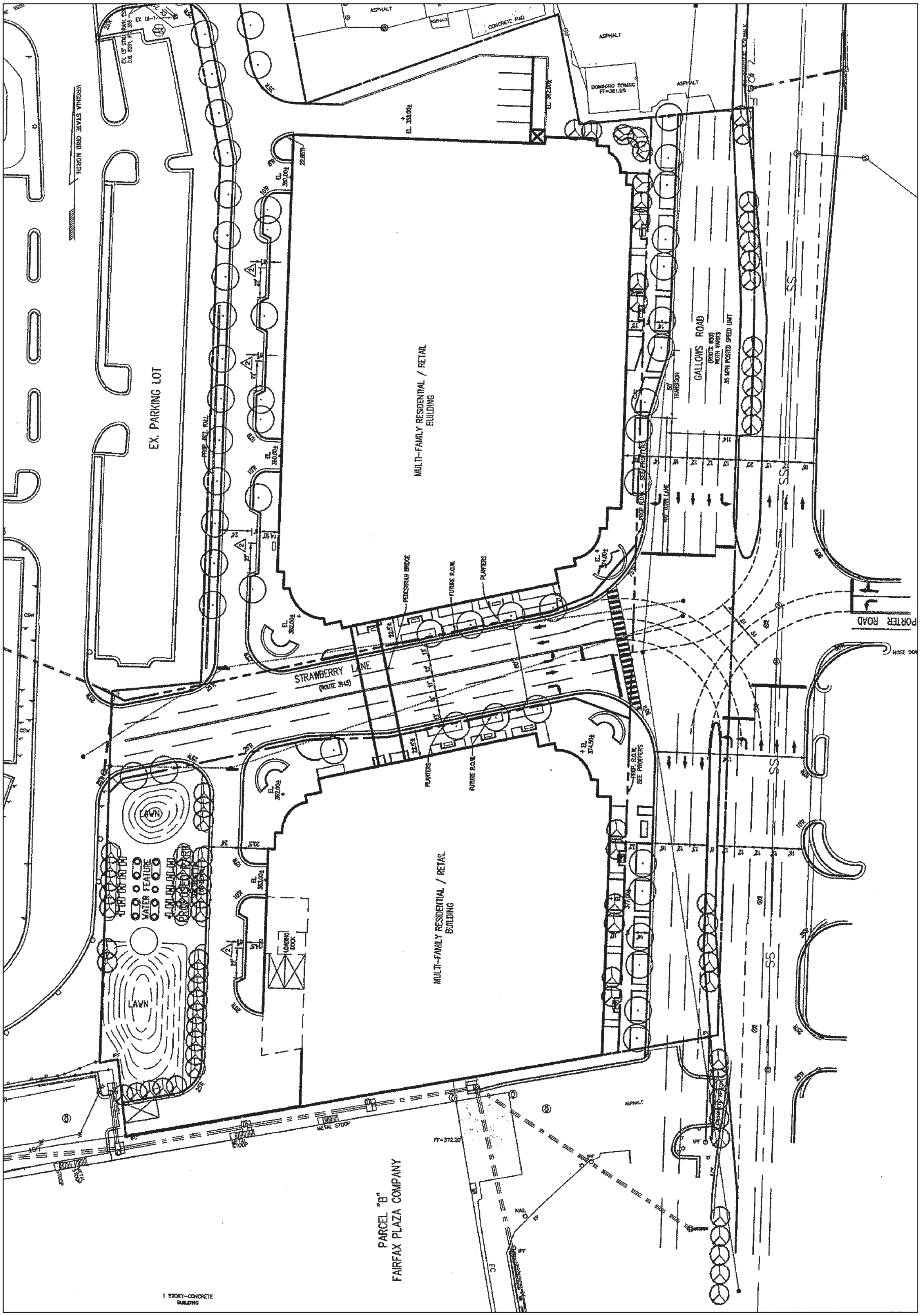


FIGURE F.10B Ultimate Gallows Road improvements.

TABLE F.1 Public Roadway Design Scenarios

	Existing	Comprehensive Plan Recommendation	Traffic Study Recommendation	Interim	Ultimate
Gallows Road	4 through lanes; single left-turn lane from NB Gallows to Strawberry	6-lane road with planted median; 26-ft to 30-ft streetscape adjacent to buildings	6-lane road; dual lefts from NB Gallows to Strawberry; single left from SB Gallows to Porter; dedicated right from SB Gallows to Strawberry	4 through lanes; dual lefts from NB Gallows to Strawberry; single left from SB Gallows to Porter; dedicated right from SB Gallows to Strawberry	Traffic Study Recommendation
Strawberry Lane	3 lanes at any given point—2 turning lanes and a through at each end of street	2 through lanes with on-street parking on both sides and 26-ft of streetscape adjacent to buildings	4-lane road with dedicated right onto SB Gallows	Traffic Study Recommendation	Traffic Study Recommendation

mately it would affect the final ROW dedication and buildable area of the site.

Utilizing VDOT's proposed centerline for Gallows, Dewberry worked with the traffic consultant and VDOT district reviewer to evaluate configuration alternatives by confirming sight distance, ensuring constructibility in interim and ultimate conditions, examining requisite signal improvements, and gauging the effects on the required streetscape facilities. This process is very much a balancing act: providing adequate public facilities while optimizing buildable site area.

Strawberry Lane. A similar balancing act was required as it related to Strawberry Lane. VDOT and the traffic consultant wanted to ensure safe, efficient vehicle movement, while the local jurisdiction and client were concerned with providing the required streetscape and pedestrian improvements without dedicating more land than is necessary. Various design configurations for Strawberry were investigated including the following:

- On-street parking as identified in the comprehensive plan was laid out but rendered moot by turning lane requirements. (See Figure F.11.)
- Provision of a brickpave median to provide a pedestrian refuge in a street that had become increasingly wide with traffic recommendations for turn lanes was eliminated, as it required an additional 4 feet of ROW dedication along the entire street.
- A curved centerline alignment was thought to better orient the street through the site between its two "pinned" points—the existing Gallows/Porter intersection and the small piece of existing ROW that allowed the connection to the existing private street to the west, but was rejected because it established a poor framework for the land bays, exacerbating the already asymmetric situation.
- A traffic circle instead of an intersection at the private access road was examined as an attractive means of directing traffic at a key focal point in the site. Further, it would have provided an acceptable public street terminus and allowed for earlier transition from private to public street access. However, in order to achieve this benefit, the circle or temporary cul-de-sac would be subject to public street design standards, which mandate a large radius and ROW dedication in order to accommodate emergency vehicle and truck access to the planned facilities. Public street sight distance requirements would limit anything in the center of the roundabout (landscaping or artwork) to less than 2 feet in height. The reduced aesthetic options, combined with the impact to the buildable area of the proposed park and land bays, were too substantial to overcome, and the circle was abandoned.

Private Service Drive. Although a private street, the service drive was a critical design element. The street was intended to be small to minimize infrastructure maintenance requirements, yet it had to meet several functional criteria: (1) garage access, (2) loading access, (3) emergency vehicle access, and (4) park maintenance. Each of these access crite-

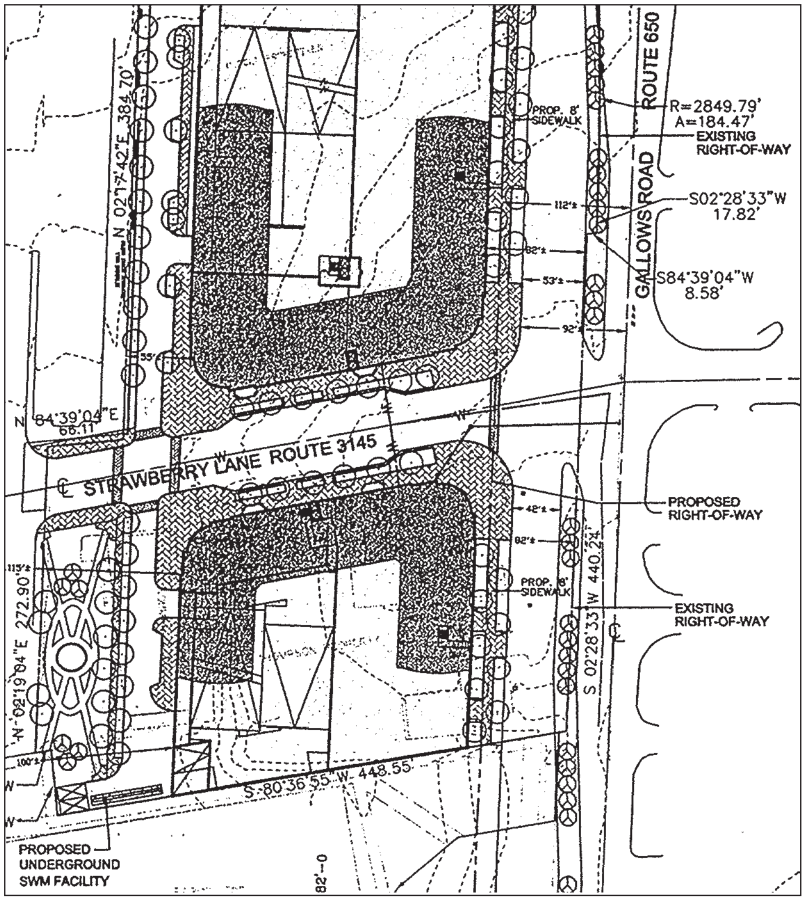


FIGURE F.11 Alternate Strawberry Lane configuration: an early version of the rezoning document showing Strawberry Lane with on-street parking.

ria was further coordinated with the pedestrian, open-space, and streetscape facilities implemented to the extent possible in uniformity with the rest of the site. Garage entrances interrupt pedestrian facilities and building facade; thus, they had to be coordinated with the grading and location of ramps, drainage structures, and usable commercial space. Loading facilities are a requirement of the zoning ordinance; confirmation that moving and/or delivery trucks could successfully access loading facilities was achieved using AutoTurn (discussed in Chapter 20). In Fairfax County, buildings over 50 feet in height must have ladder truck access to the front and rear; emergency vehicle access must be located 15 to 30 feet from the structure and have a minimum width of 18 feet. Truck turning movements dictated the minimum width of the street (see Figure F.12), while emergency vehicle considerations prescribed the location of the street. Once each of these access considerations was confirmed and the general location and dimension of the street established, the remaining details could be final-engineered pending an approved rezoning and development plan.

Environmental Considerations

Stormwater Management and Best Management Practices (BMPs). Once a more realistic building footprint and roadway configuration were established, hydrology analysis and SWM requirements were determined. For such a small site at the top of the watershed (little to no off-site water), rational method hydrology was used for modeling purposes. Although the site was developed, the proposed development program (as detailed in schematic) resulted in an 18 percent increase in impervious area. Based on this analysis, it was determined that both detention and BMP facilities would be required.

The urban nature of the site, along with comprehensive plan recommendations to use underground SWM facilities in the Town Center area (in lieu of traditional open-air facilities), led to the initial design of online, large-diameter pipe detention systems—one in each land bay. Although rooftop detention facilities were considered, they were not a feasible option from an aesthetics standpoint, since the residential towers overlooked them. This seemed like a waste of usable roof space to the client; instead of rooftop detention, Uniwest, prompted by a request from the district supervisor, asked Dewberry to investigate the possibility of a greenroof and provide information about how it might provide credit toward the water quality requirement instead.

Water quality requirements for the site were based on redevelopment criteria, since the proposed increase in impervious area was less than 20 percent (Fairfax County redevel-

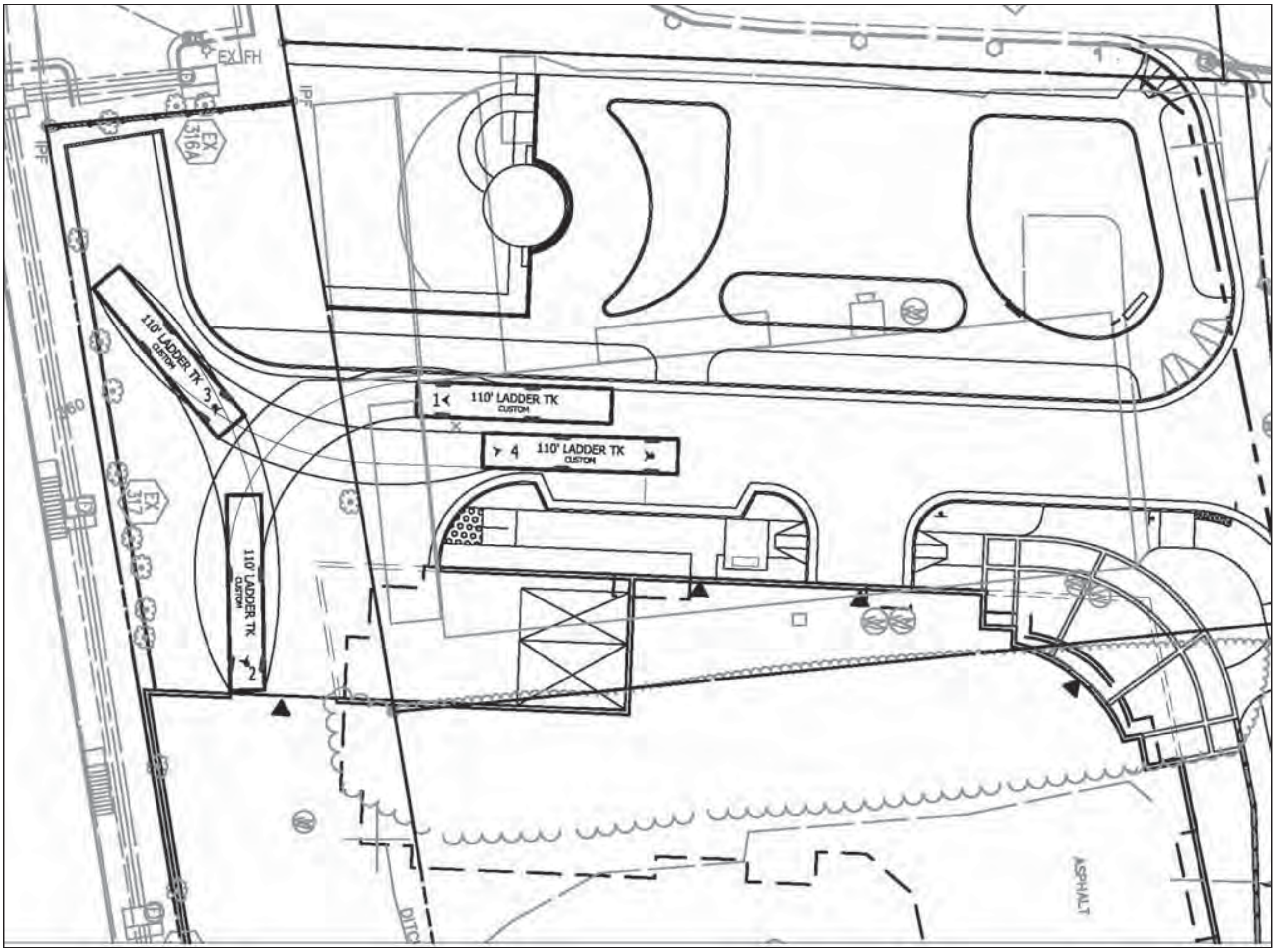


FIGURE F.12 Truck turning analysis.

opment criteria). Thus, the phosphorus removal requirement for the site was determined to be approximately 14 percent. In Fairfax County at the time of this rezoning effort, there were no guidelines for proper implementation or crediting of greenroofs as an SWM treatment option.[2] Dewberry, through a white paper to Uniwest, explained the characteristics, pros, and cons of both extensive and intensive greenroofs and developed an SWM model for the site utilizing an intensive greenroof. While the district supervisor was a strong proponent of the greenroof system, the likelihood of achieving SWM credit during the site plan review process was highly questionable. Uniwest determined that building a greenroof was economically feasible; however, the inability to procure guaranteed SWM credit led to a compromise. An intensive greenroof would be provided on a portion of each building and would be credited toward the recreational facility requirement for the residential portion of the development. In this manner, Uniwest was able to yield the benefits of an intensive greenroof as well as meet the merits of a proffered requirement, while the supervisor was pleased to see design efforts that incorporated low-impact strategies.

With the greenroof benefits applied elsewhere, SWM quality criteria still needed to be addressed. Dewberry designed an underground sand filter that would treat the bulk of the runoff. As schematic design discussions proceeded with jurisdiction staff, it became clear that an SWM treatment requirement exceeding minimum standards was desirable. Fairfax County is in the Chesapeake Bay watershed and is, like many jurisdictions in this environmentally sensitive area, conscientious of SWM and erosion and sedimentation (E&S) on all land development projects. As a precedent-setting project in the town center area, it became clear that MTC would set the standard for exceeding minimum requirements. Thus, even early iterations of the SWM design sought to achieve upward of 20 percent phosphorus removal through incorporation of innovative BMPs such as Filterra units (inlet biological filtration systems).

Landscaping/Streetscaping. The emphasis in the comprehensive plan on the sense of place to be created in the Town Center led to increased scrutiny of the proposed streetscape, landscaping, and pedestrian facilities during the schematic and rezoning phase. In order to emphasize the importance of

[2]In 2006, Fairfax County amended its *Public Facilities Manual* to include six low-impact development (LID) techniques, one of which is a green or vegetated roof system, as acceptable best management practices.

streetscape, landscaping, and pedestrian facilities, the county required Uniwest to proffer these improvements. From bike racks and benches to material specifications, maintenance obligations, and even fee-in-lieu or contribution requirements for off-site improvements, the urban design goals expressed through the streetscape were always at the forefront of design considerations. As seen in the schematic plan (Figure F.13), an alternate streetscape section was incorporated to ensure adequate open-space and pedestrian facilities regardless of the evolving road designs.

The Rezoning Process

In order to achieve the desired development program—stacked mixed use with retail, office, and residential components—the site had to be rezoned from Industrial (I) and Highway Corridor (HC) to Planned Residential Mixed-Use (PRM). Chapter 16 of the Fairfax County Zoning Ordinance outlines the review and approval requirements for rezoning to a P district, specifically, the requirements for Conceptual and Final Development Plans (CDP/FDP) to clarify the development program and support the rezoning application as well as provision of a Site Plan to carry out an approved CDP/FDP. The CDP/FDP is typically prepared by the land development consultant in close collaboration with the architect, traffic consultant, other subconsultants, and the client; it is effectively the deliverable produced during schematic design. Often, it involves several iterations and substantial negotiations between the client, the jurisdiction, and the community, as this is the document subject to public scrutiny at planning commission and board of supervisors hearings. Of particular interest, are the proffers or development conditions usually crafted during the course of the rezoning effort as a result of provisions in the zoning ordinance that make it possible for the jurisdiction to ensure public health, safety, and adequacy of services through proffers.

Although a seemingly straightforward rezoning, given the comprehensive plan language and a relatively willing community, the actual process took 13 months from initial submission to Fairfax County to final approval of the CDP/FDP and rezoning. What happened? This project, like many others, ran into the buzzsaw that is land development politics. Ultimately, translating the comprehensive plan vision and Uniwest's dream scenario into the reality of public infrastructure satisfactory to the numerous jurisdictions and citizen groups with a vested interest in the project became an exercise in patience and perseverance as well as a design challenge.

Rezoning—Negotiations with Staff. As noted earlier, the public agencies' primary concern as it related to the MTC development was related to access and connectivity improvements. Streets, functioning as the backbone of the site, are the primary conduits for people and vehicles. They serve as the frame for both the recreational and functional (building) spaces and as such must be appealing, safe, and efficient. All other site components are contingent upon the street configuration—the streetscape, utility corridors, and building and open-space envelopes are all determined in relation to the street configuration. Thus, nearly every public entity involved in the land development review process had a vested interest in the proposed street improvements. From the complete redesign of Strawberry Lane to the substantial improvements associated with the widening of Gallows Road, including an entirely new configuration for the Strawberry/Gallows/Porter intersection, iterations of the street design resulted in a ripple effect through the remainder of the site. Uniwest President Mike Collier noted, "As the public improvements began to take shape, we realized the site would be a tighter squeeze than we initially anticipated; maintaining a profitable balance between the infrastructure improvements and the allowable development program was at the heart of all rezoning and proffer negotiations." Issues such as alignment, configuration or typical section, and phasing of improvements for all three streets—Strawberry, Gallows, and, to a lesser extent, Lee Highway—were the focus of preliminary engineering efforts and proffer development.

To aid in understanding the various competing interests, a brief description of the primary entities and their goals in terms of the MTC redevelopment follows.

- *Uniwest (Developer):* Maximize buildable area within the confines of the existing site boundary and those created by the proposed ROW dedications; facilitate access to the site and create an aesthetic, safe public space to foster a vibrant community.
- *VDOT (state transportation agency):* Improve the condition of existing public roads and enhance the safety and efficiency of the public road network through implementation of current standards, limit rebuild efforts associated with future road improvements, and optimize private-entity contributions through dedications, construction, and escrow opportunities.
- *Fairfax County Department of Transportation (local transportation agency):* Ensure that the recommended roadway improvements in the comprehensive plan are carried out.
- *Fairfax County Department of Zoning (local planning agency):* Ensure that the recommended streetscape and open-space improvements in the comprehensive plan are incorporated and applicable zoning and use restrictions are adhered to.

Through design, these competing interests are resolved. The land development consultant often is the designer and mediator; the engineer and planner work in concert to recommend solutions, offer alternatives, and continualy evolve and modify the plans to accommodate the client and the jurisdiction staff. Specific items of compromise for MTC included the following.

- *Strawberry Lane:* Timing of vacation/dedication of ROW, alignment, and configuration—number of lanes, lane widths, and crosswalk material.

- *Gallows Road:* Configuration—number of lanes, lane/median widths, ROW dedication—coordinate with VDOT plans, and timing/phasing of improvements.

Many of these issues were a result of all streets remaining public entities; although this was the desired approach by all parties, it had drastic impacts on the flexibility of the street design, as, ultimately, public maintenance and design guidelines (not necessarily developed for urban streets) were the overriding factor. Within the CDP/FDP and the associated proffers, these concerns were addressed through the following:

- Alternate streetscape plans that adequately accounted for potential changes to Gallows Road were achieved through further negotiation and design during final engineering.
- Interim and ultimate Gallows Road improvement plans were developed as well as proffered contributions toward ultimate construction to ease phasing concerns.
- Correspondence indicating the collaborative process and a mutual understanding of roadway design criteria was added (see page 17 of FDP 2003-PR-009) in order to verify that the ROW dedications were adequate based on agreed-upon lane configurations.

Rezoning—Negotiations with Citizens. As is typical of the rezoning process, the development team met with the neighboring citizen groups individually to present their proposal. The issues raised at those meetings were related to specific impacts on the citizen groups including such items as uses within the proposed development, the transportation improvements, and stormwater management concerns. There was not much opposition to the proposal; however, one of the downstream homeowner associations, represented by a very vocal, active resident, persistently expressed concern that insufficient stormwater management was being provided. This particular HOA was located along the open-channel section of the downstream outfall and was experiencing significant erosion problems.

As a downstream resident, this particular neighbor felt that although this was considered a redevelopment project, a proportionate improvement in the site runoff scenario should be provided to address the downstream erosion problems, although that was not the requirement in Fairfax County. The respective requirements were such that postdevelopment peak discharge for the 2- and 10-year storms did not exceed predevelopment peak rates and a phosphorus removal efficiency of 20 percent. The initial CDP/FDP and associated proffers met the requirements of Fairfax County by providing stormwater quantity and quality control as required for a redevelopment project.

The concerned neighbor, although not a land development professional, was savvy about stormwater regulations, control options, and the land development process. This citizen effectively voiced concern, engaging both the planning commissioner and the district supervisor in project stormwater discussions. The neighbor sought a solution that controlled both the volume and the rate of runoff directed to the ultimate outfall and requested that the stormwater design for the site address smaller-frequency storms, those causing the most damage to the natural streambed, which were not accounted for in the county regulations. In an effort to compromise prior to public hearings and avoid a show of nonsupport from a neighbor, Dewberry and Uniwest collaborated with the citizen. After listening to her valid concerns, Dewberry reviewed and revised the stormwater management program to reasonably incorporate her recommendations. Given the size of the facilities required to meet baseline county requirements, Dewberry was able to determine that the additional requirements advocated by the downstream neighbor could be achieved through refinement of the control structures in the detention facilities (at little additional cost) and the incorporation of several innovative BMPs (minor cost in the scheme of site improvements) in previously untreated subsheds. Ultimately, Dewberry advised Uniwest to agree to stormwater management proffers that exceeded county requirements: BMP or quality control was to meet a 30 percent removal efficiency, 2- and 10-year detention was to reduce existing peak flows by 10 percent, detention for storms more frequent than the 1-year interval was to be provided, and sufficient detention volume for the mean annual storm was to be provided in the facilities. By incorporating these increased standards at minimal cost, Uniwest was able to ameliorate the concerned citizen, improve its good-neighbor status, and set a precedent encouraging future development in the area to exceed baseline environmental standards for the benefit of the entire Merrifield community.

Rezoning Revisited—the Art of Compromise. The art of compromise was successful in this particular instance, as all parties involved attained all or the majority of what they initially were seeking. Uniwest received full support of the community, staff, and decision makers for their rezoning application, which included the bonus density for provision of ADUs. The citizens were successful in gaining the approval of the first phase of the much wanted Town Center without compromising infrastructure improvements and, in fact, set a precedent for redevelopment conditions that exceed local requirements. Local politicians were praised by the community for their efforts to unite the community and developer through reasonable and forward-looking proffer agreements that embraced the urban nature of the Town Center.

After one year of negotiations in the rezoning process, the property was rezoned by the board of supervisors (by a unanimous vote from 6 out of 10 present for the vote) to the PRM District to permit the development of the MTC project as we know it today. The development of the property was proffered to be in conformance with the approved CDP/FDP, as shown in Figure F.13.

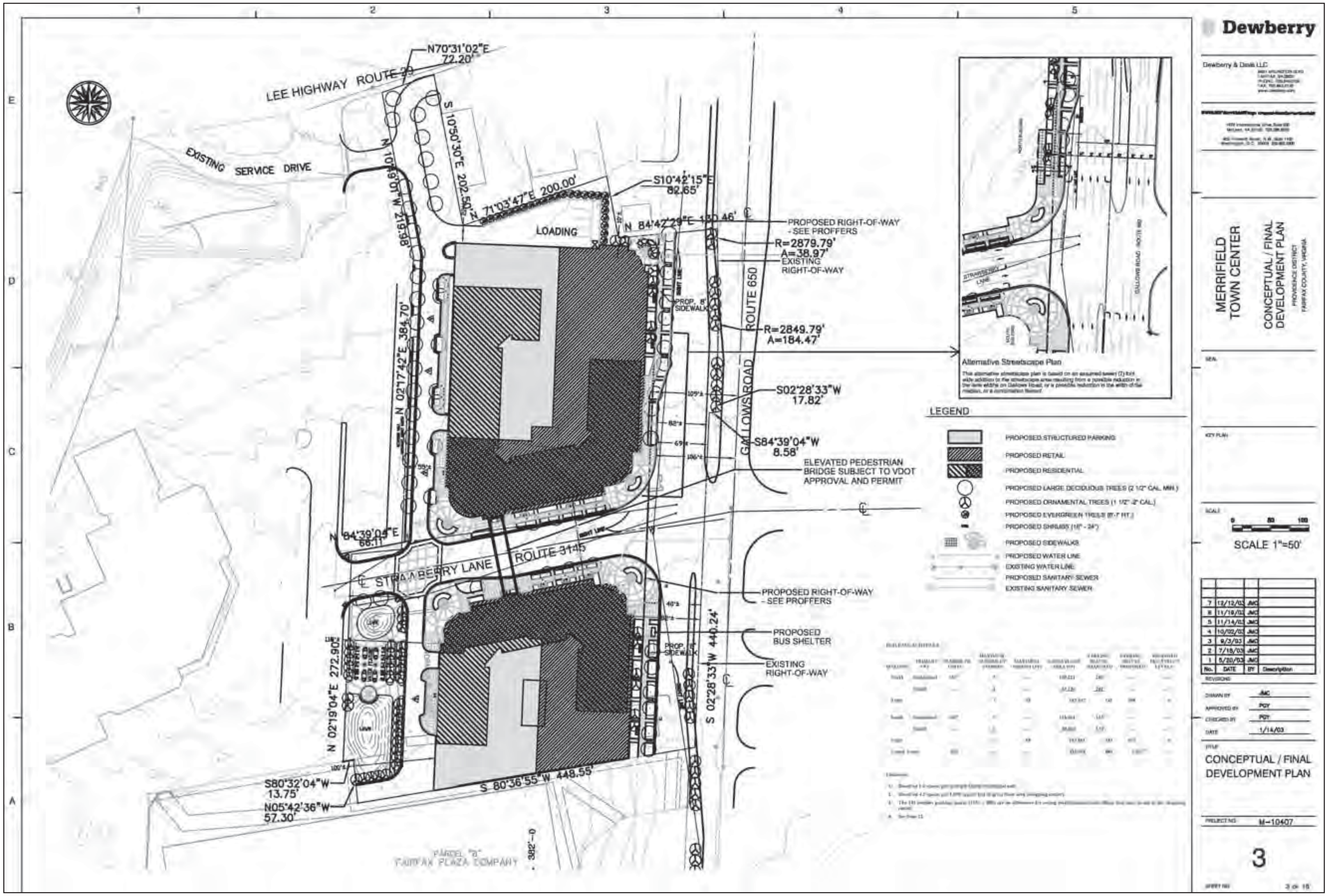


FIGURE F.13 Approved conceptual development plan/final development plan.

Noteworthy proffers included the following:

- Maximum density including 270 residential units and a site FAR of 1.35 with the increase over the base of 1.2 dedicated to ADUs
- Restriction of various uses within the retail component of the project
- Monetary contribution to the local schools—elementary, middle, and high school
- Recreation contribution through provision of on-site facilities including rooftop amenities or contribution to the Fairfax County Park Authority (FCPA)
- Provision of bicycle racks and benches
- Architectural compliance proffers to ensure consistency with CDP/FDP in terms of material specification, building height, and energy efficiency standards
- Construction, installation, and maintenance of all SWM facilities necessary to meet enhanced quantity and quality criteria included in the proffer
- Installation and maintenance of landscaping along Gallows Road and Strawberry Lane
- Noise attenuation interior to the building and in rooftop amenity areas
- Streetscape including adequate lighting and pedestrian facilities
- Implementation of Transportation Management Strategies (TMS) including specific time frames for which to monitor and achieve single-occupancy vehicle (SOV) reduction goals with monetary contribution assigned for noncompliance
- Provision of shuttle bus service to the Dunn Loring metro station or contribution to such service provided locally
- Construction and maintenance of traffic-calming devices in the form of stamped crosswalks
- Construction of or escrow toward a bus shelter
- Dedication of ROW for Gallows Road ultimate improvements, construction of interim improvements, and escrow for the difference in cost between interim and ultimate
- Vacation of existing Strawberry Lane ROW as well as construction and dedication of realigned Strawberry Lane
- Signalization modifications at the realigned Strawberry/Gallows intersection including provision for easements and escrows toward ultimate signal requirements
- Contribution to Eskridge Road improvements
- Notification proffers providing for supervisor and planning commissioner review of construction documents

From these proffers, the project goals are evident: density, mixed usage, and affordability in the Town Center area; transportation improvements with a focus on feasible transit options; and adequate public facilities including localized open space and recreational opportunities for the newly developed residential population.

PART V: FINAL DESIGN

Using the approved rezoning and CDP/FDP as a basis, and in accordance with zoning ordinance requirements, a site plan was prepared. While much of the design was formalized during the schematic phase, the final design effort focused on the technical details and implementation of the proffered elements. The emphasis of this case study is the land development process; since the intricacies of final design are fairly technical and were covered extensively in previous chapters, a summary of noteworthy site plan components is included to simply illustrate the type of refinement, detailing, and scope of changes that can occur during final engineering.

Street Design

- Accurate vertical geometry was provided for realigned Strawberry Lane.
- Signal modifications at Gallows Road and Strawberry Lane/Porter Road were required in both the interim and ultimate conditions. By allocating space and ROW for the ultimate signal configuration, entry monumentation, grading, and landscaping could be designed and installed with minimal disturbance anticipated during ultimate buildout.
- The design of the private access drive was refined to include mountable curb for park maintenance as well as handicap-accessible streetscaping. Further, public access easements were delineated to encompass emergency vehicle turnaround needs at the south land bay terminus and the intersection with Strawberry Lane.
- Sight distance verification was performed for interim and ultimate improvements to Gallows Road as well as confirmation from the private access drive to the signal on Gallows to ensure that it is visible below the pedestrian bridge.

See Figure F.14.

Grading and Earthwork

- Provision of a second left turn lane from northbound Gallows Road to Strawberry Lane resulted in a taper (to receive dual lefts) that forced grading and landscape modifications to the sidewalk and receiving area outside the main entrance of the north building. A combination of ramps, stairs, and planters resulted in an aesthetically

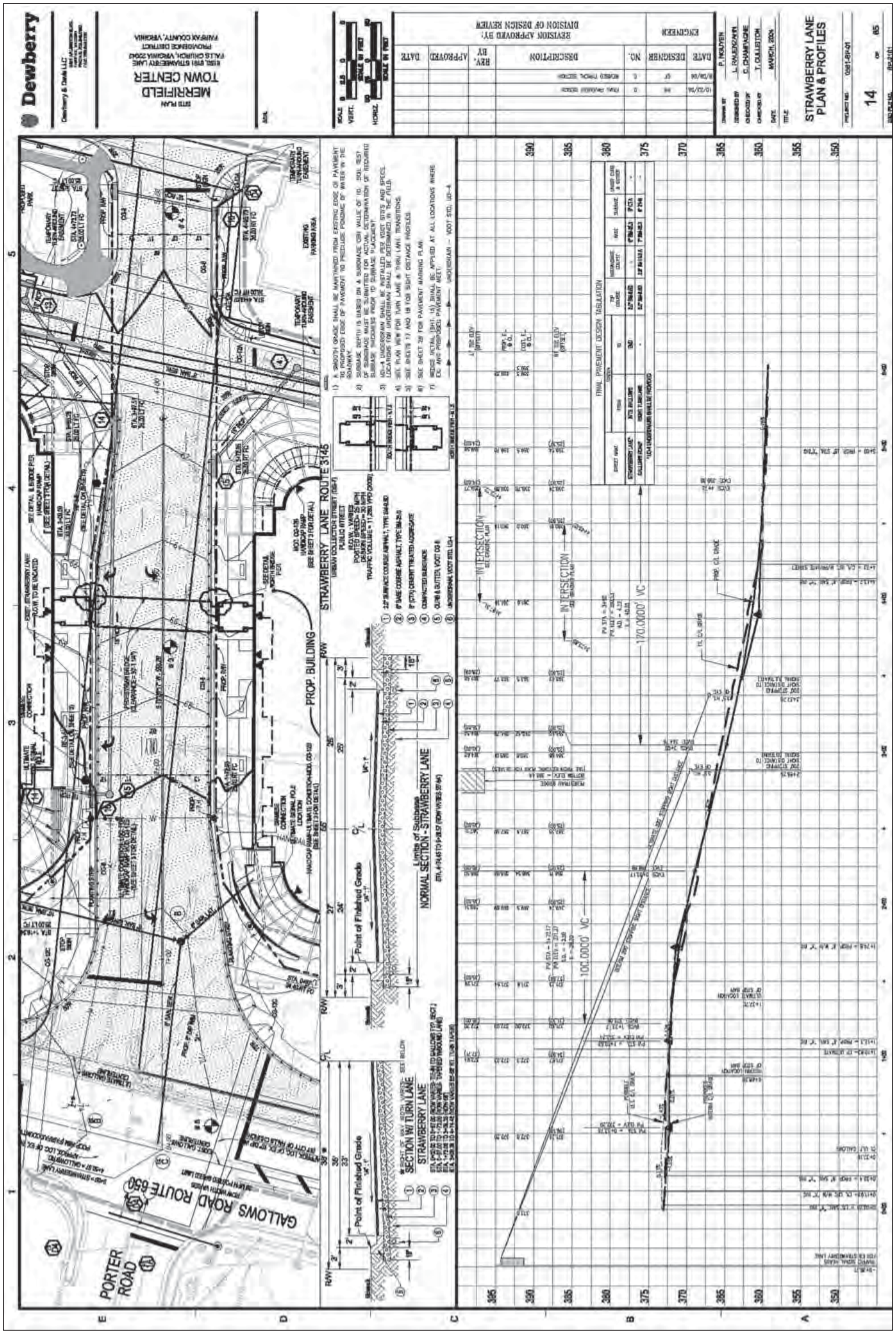


FIGURE F.14 Strawberry Lane plan/profile.

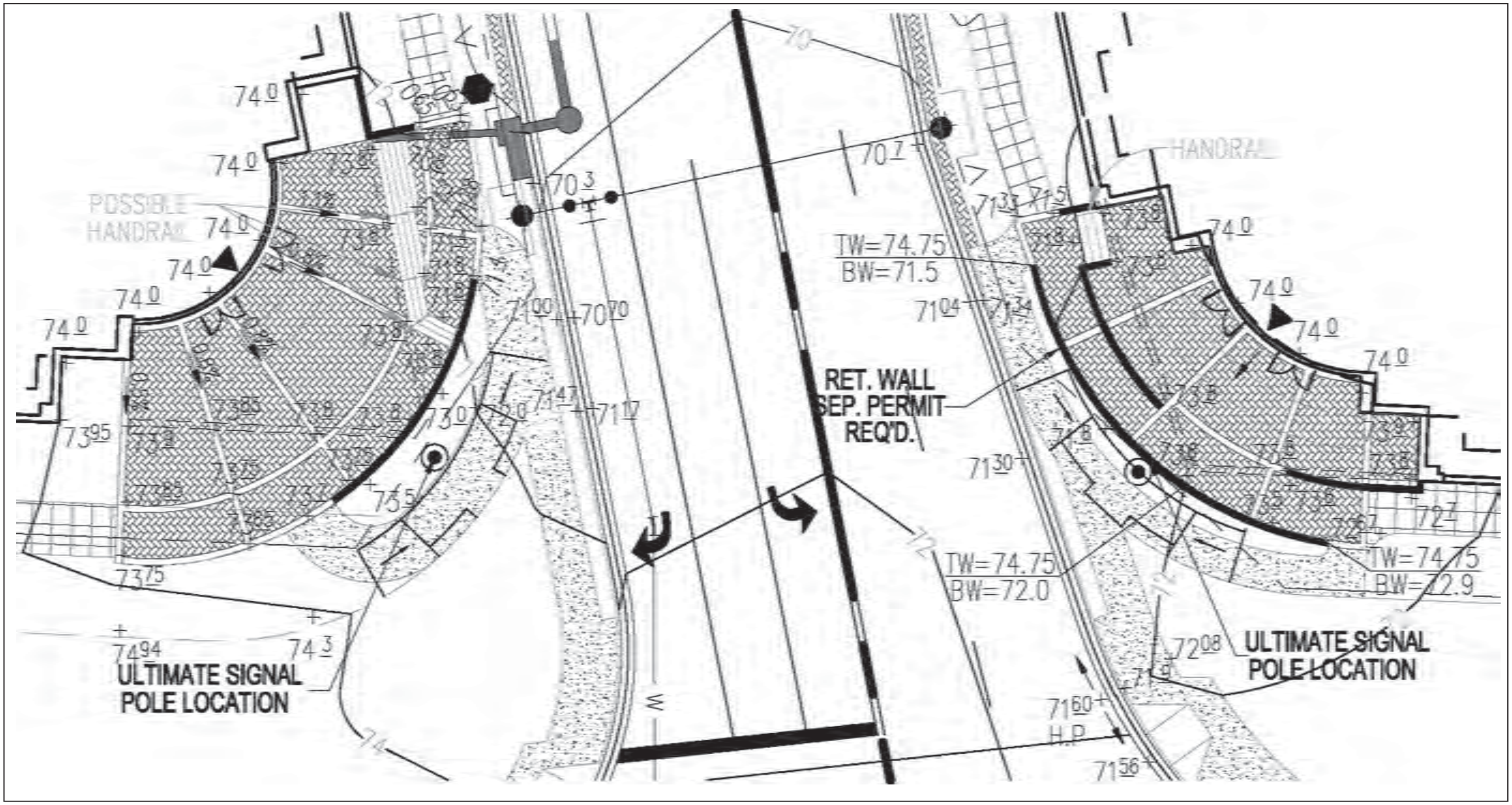


FIGURE F.15 Gallows/Strawberry corners—main entrance grading modifications.

pleasing, interactive area at the primary entrance to the development. See Figure F.15.

- Once the vertical geometry for Strawberry Lane was set, additional modifications were made to provide a safe landing area at the Gallows/Strawberry intersection. Provision of the landing created a steeper tangent, 4.97 percent, along Strawberry. Handicap accessibility standards dictate a 5 percent maximum longitudinal slope; thus, it can be seen how tight and precise the final engineering plans were in order to meet both vehicular and pedestrian criteria.
- West of the north land bay between the site and the adjacent parking area, 280 feet of retaining wall was removed, representing a significant construction cost savings.

Stormwater Management Design

- The south land bay detention facility was transformed into a detention vault rather than a large-diameter pipe system as warranted by space, volume, and economic considerations for the final size of the facility. See Figure F.16.
- SWM facilities were consolidated in the north land bay into a single sand filter that provided both detention and treatment for site runoff. This represents savings in terms of space as well as construction and maintenance costs.
- Filterras designated in the CDP/FDP (schematic plan) were relocated to the south land bay adjacent to the park, where they were a more practical, aesthetic fit and more aptly positioned to treat runoff not directed to the northern sand filter.

Utility Coordination

- Provision of a right turn lane from Strawberry Lane to Gallows Road created a conflict between the storm sewer system and the proposed streetside landscape areas. Compromise with VDOT allowed placement of storm sewer in the public ROW, thus maintaining the streetside landscaping along the entire length of the turn lane.
- The storm sewer outfall for the northern SWM facility was originally directed through the adjacent property, requiring an off-site easement; when this easement could not be amicably procured from the adjacent property owner, the SWM facility was redesigned to orient the clearwell and outlet pipe through an existing storm sewer easement.
- To meet fire hydrant coverage criteria, an additional hydrant was added west of the north land bay. The intended connection was an existing waterline in the Hilltop ROW; thus, an off-site easement from the same neighbor was an issue. The line was redesigned to tap an existing line in Lee Highway; however, this connection

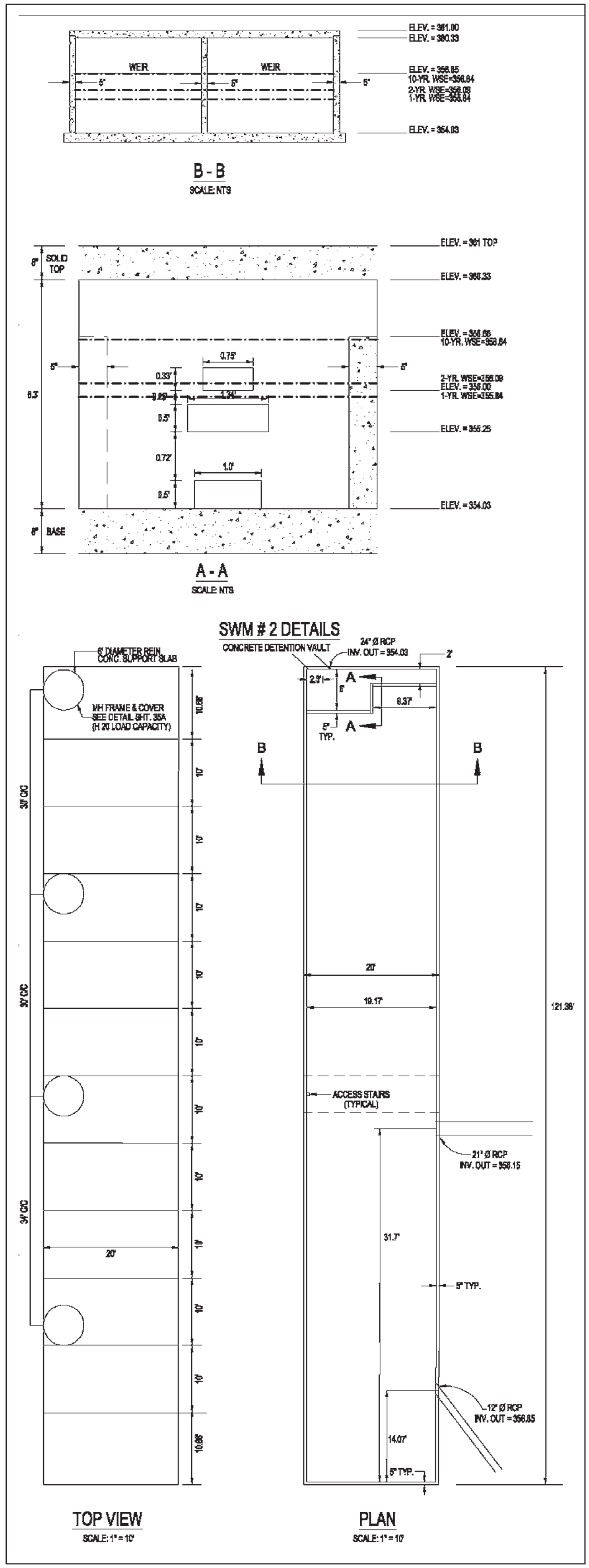


FIGURE F.16 SWM details for underground detention vault.

resulted in gas line and utility pole guide wire conflicts. Coordination efforts with both the gas and electric companies (already relocating facilities in the area to accommodate the project) resulted in an amicable resolution wherein both the water and gas lines were shifted to create the necessary clearance and still make the connection.

- Space for electric transformers was provided in the park area and the north loading dock. Screening was implemented in the park, and the north loading dock was reconfigured to provide additional space and meet utility access requirements.

SUMMARY: PROFFER COMPLIANCE

Likely the most important component of final engineering, proffer (or condition) compliance is the mechanism by which the technical review staff at the county ensures that the site plan fully implements the approved planning (entitlement) document. The site plan should indicate "how, when and where the proffer was, or will be, satisfied, the status of proffer 'triggers,' and deviations from proffers and/or development plans,"[3] often through narrative form. See Figure F.17, a representative sample of a single proffer compliance illustration. In the case of MTC, clarifying which proffered improvements were designed and constructed as part of the site plan, versus deferred or versus escrowed as a result of project phasing considerations, was of paramount importance. A clear understanding of the status of proffered agreements between Dewberry, the site plan reviewer, and the client allowed for smooth plan processing, bond posting, construction, and occupancy permit procurement.

As a final note, the expeditious completion of the design process—feasibility through final engineering—and the successful, cost-effective design and construction of the project can be attributed to the proactive, team approach utilized by Uniwest. The general strategy for completion included the following:

- The same consultant was used to perform the surveying, planning, zoning, and engineering tasks, thereby providing continuity to the design process.
- Overall schedules and priorities were established with senior management at Dewberry, while specific issues were addressed jointly by staff within Uniwest, Fairfax County, the architectural firm, and Dewberry, the land development consultant.
- Weekly meetings and daily interaction between the developer and the design professional were maintained throughout the life of the project.
- Uniwest was both the developer and the contractor; thus they were able to review plans and help develop strategies to reduce costs during all phases of the design process.

[3]DPWES Letter to Industry #06-15. July 24, 2006.

PART VI: PLAN SUBMISSION AND PERMITTING

Plan Review, Approval, and Permitting in Fairfax County

The review and approval of the final engineering documents requires the involvement of local and state governments, the client, and the design consultant. To better understand the review and approval process as it relates to Merrifield Town Center, an understanding of the participants, their role, and the structure of the process in Fairfax County is required.

In Fairfax County, the governing body, the board of supervisors, is ultimately responsible for the review and approval of all engineering plans and plats as well as inspections and monitoring during project construction. However, the board has delegated these tasks primarily to the Department of Public Works and Environmental Services (DPWES) and its director. The director is authorized to review and approve construction plans and plats on behalf of the board. DPWES, in turn, relies on the input from other agencies and departments within the county government—Transportation, Housing Authority, Health, Fire Marshal, and Park Authority, to name a few—as well as other local and state agencies, such as the Falls Church Water Authority, VDOT, and the Department of Conservation and Recreation, in the review of engineering plans. Depending on the issues that surface during the review process, other agencies, both state and local, may be asked to review the plans. The review agency must ensure that all projects consistently comply with published standards and policies and that the project does not endanger the health, safety, and welfare of the public or the environment.

Within DPWES, there are several divisions involved in the design/construction review and approval process. Specifically, the Environmental and Site Review Division (ESRD) is responsible for the review and approval of construction plans and plats, as well as other studies, reports, and miscellaneous items relating to the land development process. ESRD is composed of Urban Forestry, Site Plan Review, and Plan Control. MTC is located within the Providence District; that district reviewer serves as the central coordinator for each project. Other agency reviews are processed through this individual.

Rough Grading Plan (RGP)

At the time MTC was being developed, the time frame for review and approval of construction plans in Fairfax County, even when utilizing the expedited review process, was approximately 10 to 15 months. The client, Uniwest, served as owner, developer, and general contractor, and it was their intent to significantly expedite the design review and approval process to begin construction as quickly as possible. Uniwest's ability to commence sales/leasing was contingent upon site plan approval, preliminary condo plat approval, and a site permit. Showing progress, in the form of demolition and earthwork, was necessary in order to entice and convince an eager, hot real estate market to buy into the

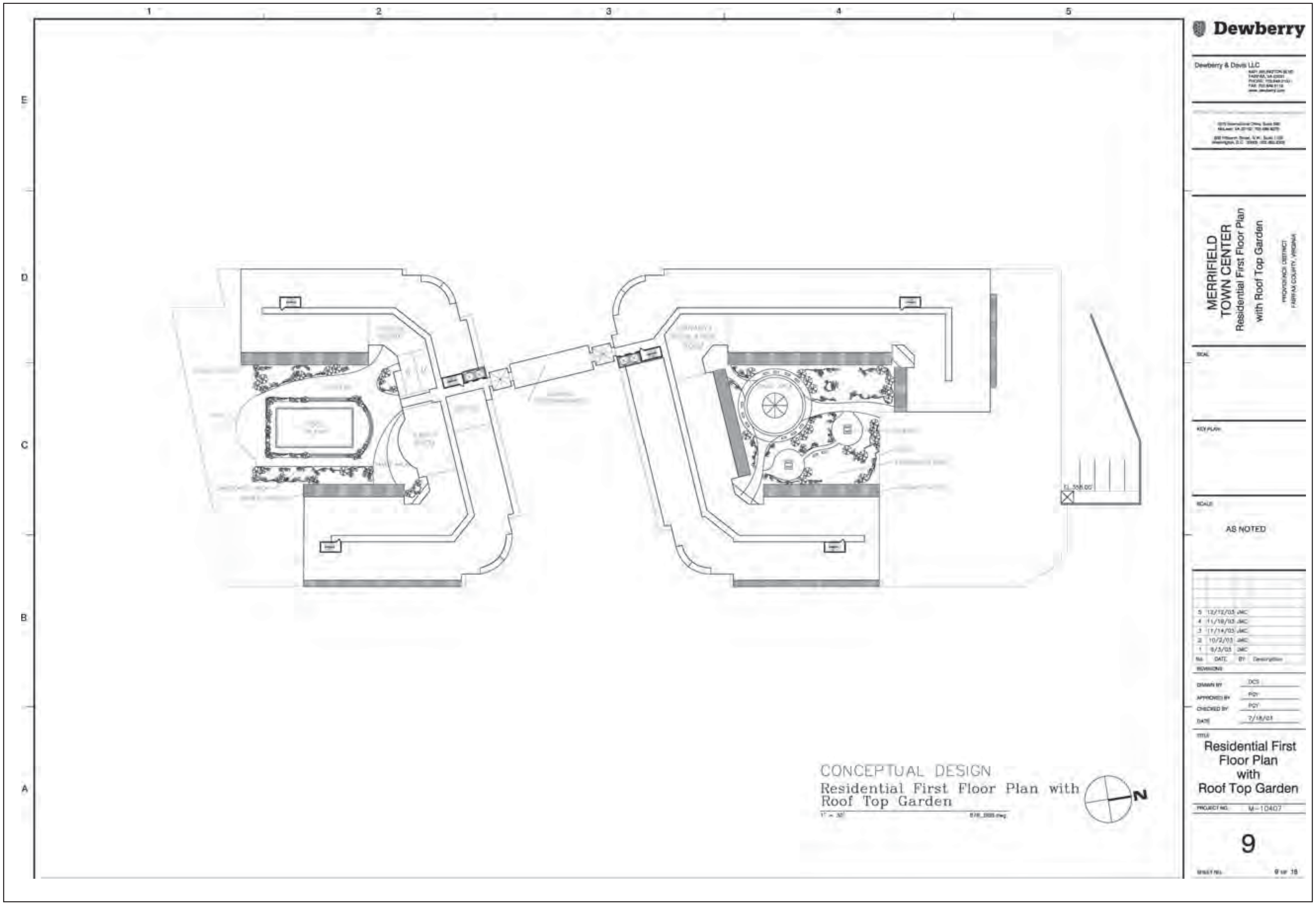


FIGURE F.17A Intensive greenroof proffer compliance illustration: rezoning and proffer development.

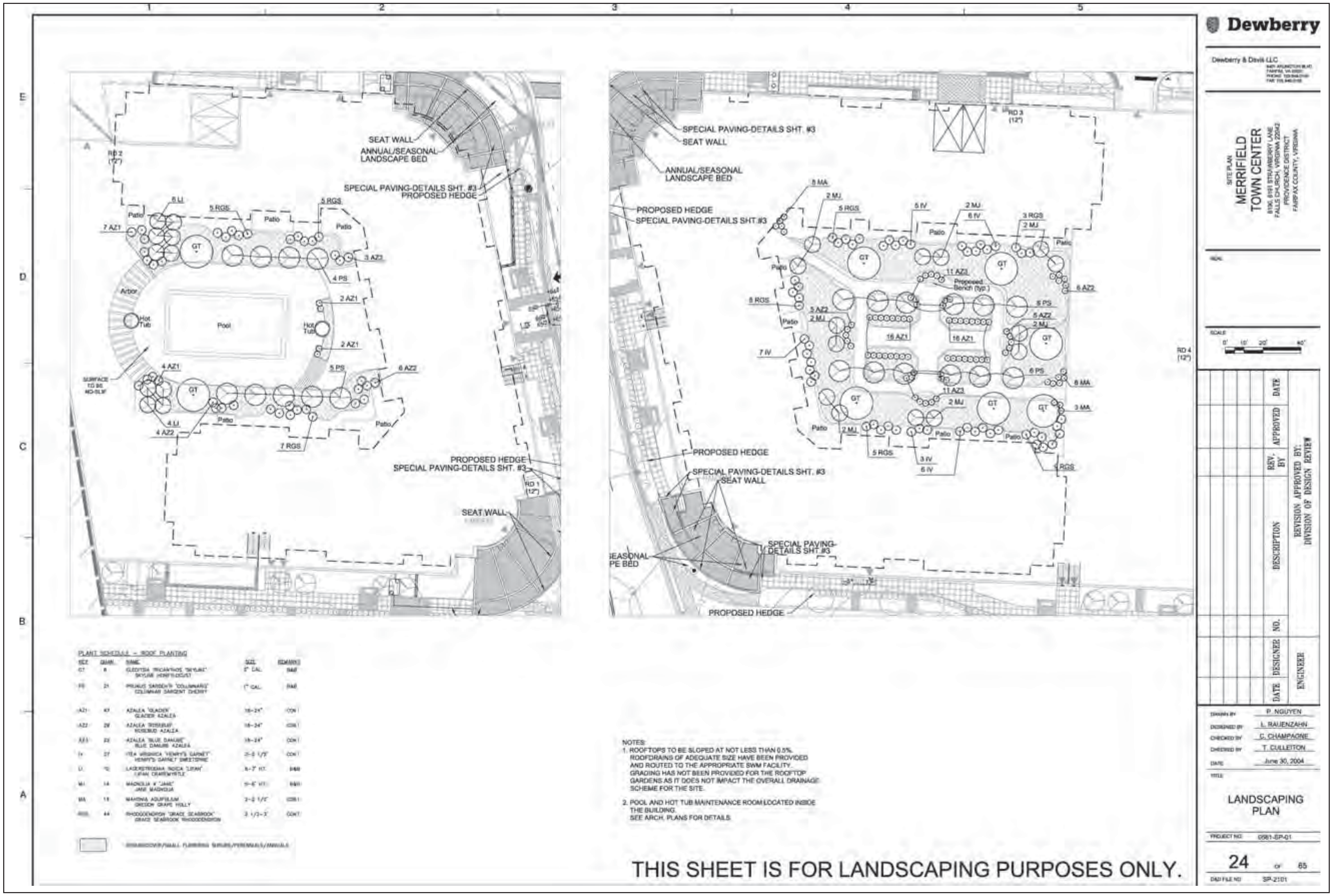


FIGURE F.17B Final engineering and site plan approval.

condominium portion and give retail and office tenants a firm idea of delivery schedule and space arrangements.

Given the lengthy rezoning process, the projected time frame for full site plan review and approval, and escalating construction costs, Dewberry advised Uniwest to utilize a rough grading plan (RGP) and permit in order to maintain the desired sales and construction schedule. An approved RGP would grant Uniwest access to the site in order to establish perimeter erosion and sediment controls and begin clearing, grading, demolition, and construction work up to and including the installation of sheeting and shoring of footings and foundations for the buildings. The RGP filled a critical gap in the plan approval time frame, allowing an early window for sales and base site work while actively bridging the otherwise stagnant time between site and building design, permitting, and construction activities. See Figure F.18.

Site Plan Approval—Building Permit

While the RGP allowed Uniwest access to the site, the bulk of the construction—both the site infrastructure and buildings—could not commence without an approved site plan and building permit. The RGP provided valuable time for Dewberry to finalize the site plan with ESRD, including such things as waiver approvals, outside agency coordination and approvals, plat preparation, and fine-tuning of site-building system interfaces. Although Dewberry had coordinated extensively with the architect throughout the design process, it is at this stage that all the details are truly flushed out, as the site plan and building plans are married for permit purposes.

Upon site plan approval, the entire project is moved to bonding—the final step in the Fairfax County approval process. The bond package contains the final infrastructure and conservation bond requirements as well as a thorough proffer analysis identifying any and all contributions, escrow amounts, and dedications to be posted by the owner. The land development consultant is typically responsible for producing the bond estimate and often works with county staff to ensure its accuracy and adjust bond prices accordingly, based on market conditions. Once the owner/developer has met or addressed all bond obligations, including both monetary and preconstruction proffered items, permits are released and construction can fully commence.

The land development consultant is a valuable resource during the bonding process as they are often able to keep the bond estimate reasonable as well as work with the client (owner) and county staff to clear or remove proffered conditions, particularly design-oriented conditions, quickly and efficiently, given their in-depth knowledge of the plans and project intents. In the case of MTC, the engineer was able to negotiate the bond status of several proffered conditions with the county site plan reviewer, either removing them entirely because they were achieved in the plan or successfully deferring them from preconstruction to postconstruction conditions. This facilitated a smooth transition from design to construction, allowing Uniwest to quickly fulfill its obligations, pull site and building permits, and arrange finances to cover construction and proffered commitments.

PART VII: CONSTRUCTION

Often construction represents the last step in the land development process (the real estate development process often considers marketing, sales and leasing, and operations and maintenance as steps, too). Consistent, timely communication among the client, engineer, contractor, and even the planner is critical to ensure that the plans are built as specified. Conflicts will inevitably arise. Some can be resolved through *requests for interpretation* (RFIs) or shop drawing submission, review, and approval iterations; others necessitate plan revisions and can become contentious and even costly if not resolved effectively among members of the design and construction team.

MTC was rather unique in that Uniwest, as noted, served as both the developer and the general contractor. Thus, familiarity with the project and a long-standing relationship (over two years of constant interaction) with the design team fostered an amicable, productive construction relationship.

Requests for Interpretation (RFIs), Field Adjustments, and Plan Revisions

RFIs for MTC ranged in nature from simple plan clarification questions to design modifications such as removing retaining walls, adding outdoor seating areas, relocating doors or steps, and finalizing details related to postdevelopment proffered conditions. RFIs related to plan clarification were resolved through provision of additional details, small exhibits, and/or quick on-site conferences to provide further direction. Many of the RFIs involving a design modification arose in response to tenant outfit requests: as retail space was leased, the internal and external configuration of the buildings and infrastructure had to be modified to accommodate specific uses.

For instance, the MTC site plan was designed based on the premise of a large two-story grocery-type tenant in the north building with smaller retail establishments in the south building (PB and PC levels of both buildings) and offices on both PA levels. Ultimately, the north building became home to a gym and two restaurants, and the south building similarly has two restaurants and office space. While these uses were allowed within the new zoning (PRM) and specifically accounted for in the proffers relating to building usage, some of the infrastructure components of the site required modification:

- Additional grease traps to accommodate increased food preparation and disposal facilities were required and added to the on-site sanitary sewer system.
- The streetscape, initially designed for a window shopping experience, had to be modified to accommodate dining and lounging in the active pedestrian areas.

FIGURE F.18 Rough grading plan.

- Doors and stairs had to be added and shifted in order to meet individual tenant access and code requirements.
- Parking requirements and provisions had to be reexamined under these alternate usage scenarios.

The challenge with regard to RFIs involving design modifications is understanding the extent to which field revisions can be accommodated within the context of the approved site plan and zoning documents. Substantial modifications must be accomplished through formal plan revisions and may require new waivers, zoning interpretations, permissions, or easements. The land development consultant, as trusted advisor and technical expert, should examine each request and make the appropriate recommendation in terms of accommodating the RFI through either a field adjustment or a formal plan revision.

During the course of construction at MTC, several formal plan revisions were completed. Many were in response to specific tenant fit-out requests, others were common to the development process in Fairfax County, and some were in response to issues that arose during construction. Table F.2 briefly describes the formal revisions completed as part of the MTC project and the triggering action.

Successful revisions balance client schedule demands with local procedure and help maintain the developer's (and contractor's) good-neighbor image by resolving construction discrepancies or issues in a safe, efficient, legally binding manner.

PART VIII: SUMMARY OBSERVATIONS

A redevelopment project in a changing suburban environment where density, sense of place, and adequate public facilities have emerged as community priorities, Merrifield Town Center is typical of the changing land development industry. It exemplifies the market-driven shift from post-World War II to post-9/11 through both its programming and its design considerations. Further, the Merrifield Town Center project incorporated all the elements of the development process from planning and zoning through final engineering and construction, effectively demonstrating the tremendous amount of outside influences involved in the planning and engineering of a major land development project. A comparison of the site before development and after development is shown in the MTC color insert sheet along with other design renderings and postdevelopment photos.

The overwhelming success of Merrifield is evident in its record sellout rate. In 2005, Uniwest received recognition for Quickest Sell-Out in the Washington metro area when the units sold out within three months of ground breaking before anything reminiscent of a building even took shape. This is not only an indicator of an exceedingly accurate market assessment by Uniwest but confirmation that the community embraced the project goals and overall vision for the site and the upcoming Town Center. The Merrifield Town Center project represented the promise of what was to come in this part of the county. Early condo buyers were hardly taking a leap of faith if, as many believed, MTC would eventually evolve into its own version of similar mixed-use projects in nearby Arlington County, such as Shirlington Village, the communities of Ballston and Clarendon, not to mention nationally recognized Reston Town Center just west of the site in Fairfax County. Some might say, what is the clamor about? It's about ease of access—to transit, to primary transportation corridors, to basic community services—and more than access, it's about a return to community and the sense of belonging to a vibrant, healthy community that draws people in, whether it's work, home, or just a visit. Merrifield laid the groundwork for the Town Center by establishing a series of compatible uses, decorative site features, and improved open space, creating a welcoming and engaging environment that established Merrifield Town Center as a desirable place to be.

While the spirit and general aesthetics of Merrifield Town Center may have mimicked some of these town center predecessors, the context of the project and the requisite design response were entirely unique. As the precedent-setting project in this area, Merrifield established programming and design criteria that would filter through the next several years as the redevelopment effort rippled through the designated Town Center area. Unlike the Arlington sites that were firmly established in a fairly urban environment and the Reston site, which was master planned and installed (at least the core) as a cohesive whole, Merrifield was truly set in an aging suburban context and was subject to the rules, ordinances, and standards developed with typical World War II suburban communities in mind, particularly as it related to public road standards. The design dichotomy of Merrifield is evident throughout the plan: the urban, pedestrian-scale goals of the comprehensive plan versus the reality of suburban traffic— and vehicle trip–driven design standards. Although the streetscape requirements of the comprehensive plan were implemented in terms of the pedestrian facilities (truly a step in the right direction and of value to the development), the streets themselves are based entirely on traffic scenarios and public street standards. From large curb returns and wide travel lanes to standard (rather than aesthetic) public streetlighting, no on-street parking, and removal of planted medians, the street sections hardly resemble the intent of the comprehensive plan. That is not to say that these exclusions or modifications to the road network were not founded in sound engineering principles (things like sight distance, design speed, queuing, and capacity issues are all based on public safety criteria); however, the application of these criteria is in direct conflict with the design and program intent. The resolution of this conflict was at the heart of the Merrifield project from day one and was the driving factor in the site design effort.

Within the land development community, the value of the Merrifield Town Center project was its ability to expose these competing issues and bring all parties—Fairfax County, VDOT, the community, and consulting professionals—back to the drawing board. Subsequent to approval and construc-

TABLE F.2 MTC Revision Summary

Revision	Summary of Plan Changes
A	1. Changed the size of the storm sewer from 15 in. to 18 in. between structures 3 and 2 and structures 2 and SWM 1A.
	2. Removed the roof drain draining to structure #8.
	3. Added 1½-in. waterline to service the fountain.
	4. Revised the drainage divide for area C9.
	5. Revised the storm sewer and associated computations due to the removal of RD4.
	6. Revised storm sewer between structure #2 and the sand filter.
B	1. Added storm interceptor detail.
	2. Revised the use group, type of construction, and building height.
	3. Added RD4 roof drain with storm interceptor.
	4. Revised drainage divides on building.
	5. Revised storm crossing on sanitary profile.
	6. Revised the storm sewer and associated computations due to the addition of RD4.
	7. Revised the access type to the SWM vault.
	8. Added detail for alternate frame and cover for SWM vault.
C	1. Revised the urban park and grading.
	2. Added exterior seating areas and additional grease traps to accommodate additional restaurant space. Revised urban park plantings.
D	1. Added outdoor seating area per the approved interpretation graphic.
	2. Added grease trap to the north and south sides of south building; details included.
	3. Revised water main D in Route 29 due to conflict with existing gas line.
	4. Revised landscaping in urban park area based on FCPA comments; new park details.
	5. Revised retaining walls along Gallows Road and the park.
	6. New sheet showing approved CDP/FDP interpretation to allow outdoor seating.
E	1. Revised parking tabulation to match updated building use square footage.
	2. Added ADU chart per request of Fairfax Housing Authority (FHA).
	3. Added a door (exit) to the Gallows Road side of the north building per tenant fit-out.
	4. Revised building tabulations to reflect corrected ADU mix and final use square footages.
	5. Additional 12-in. RCP pipe from existing inlet 7A to proposed storm structure 7.
	6. Revised the limits of clearing and grading to accommodate new 12-in. pipe.
	7. Additional silt fence for perimeter control around proposed 12-in. pipe.
	8. Revised proposed drainage divides to account for Structure 7A.

TABLE F.2 (*Continued*)

Revision	Summary of Plan Changes
	9. Revised size of grease trap connection (8-in. to 4-in.) to match MEP plans.
	10. Revised storm computations for new 12-in. pipe, Ex. 7A-7.
	11. Revised storm profile to include proposed 12-in. RCP from Ex. 7A.
	12. Revised parking layouts/counts to match update tabulation.
	13. Included letter of permission for off-site work.
F	1. Revised parking tabulation (parking counts corrected to match building plans; retail square footage corrected to reflect allowable per proffer secondary-use square footage of 105,500 ft^2—note typo in rev E of 105,550).
	2. Remove compactor from north loading dock.
	3. Add 2 surface parking spaces to north loading dock.
	4. Revised stair and wall configurations at the 4 major corner entrances to the retail.
	5. Revised curb and gutter grades on eastern side of access road just north of the intersection with Strawberry Lane.
	6. Add storm sewer easement from structure #7 to #2 to account for conveyance of off-site water from Becker property (a separate easement plat has been submitted).
	7. Revised stair and wall configurations at the 4 major corner entrances to the retail.
	8. Removed retaining wall in southwest corner of site.
	9. Revised retaining wall grades in southeast corner of site.
	10. Revised parking layout to match building plans.
	11. Included interpretation approval letter.

tion of MTC, the Providence District initiated a focus group to examine the implementation of the comprehensive plan urban design goals for Merrifield: which components were successful, which failed, where implementation is achievable, and what factors are prohibitive to realizing the desired outcome. This effort, spearheaded locally, should improve the subsequent phases of redevelopment in the Town Center area and in Fairfax County.

The success of this project was due, to a great extent, to the development team that was established and its technical, communication, and negotiation skills. It is unrealistic to believe that a project can be approved through a public process without negotiation and compromise on a wide variety of issues. In the case of Merrifield Town Center, compromises were made in the planning, zoning, and engineering elements of the development. However, the issues were thoughtfully anticipated, and, consequently, the compromises were disruptive but not fatal to the project. As demonstrated in this study, ongoing effective communication among *all* participants in the process was essential to the success of this project.

When planning and designing a project, consideration must be given to the possible impacts of the proposal on the existing community and environment. Again, in the case of Merrifield Town Center, anticipation of the issues and communication with the appropriate interest groups took place early and were kept up throughout the development process, continuing even after the project was built, in order to ensure ongoing improvement to the process and the built environment in subsequent projects. Although technology is ever advancing and changing, the human element remains paramount in the success of a given project. The human element was clearly responsible for the successful planning, engineering, and development of the beautiful start to the Merrifield Town Center.

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Appendix G
Technical Appendix

Properties of Water in U.S. Customary Units							
				Viscosity*			
Temp. (°F)	Density (slugs/ft^3)	Specific Weight (lb/ft^3)	Heat of Vaporization (Btu/lb)	Absolute (lb-s/ft^2)	Kinematic (ft^2/s)	Vapor Pressure (in. of Hg)	Vapor Pressure (lb/in^2)
32	1.940	62.418	1075.5	3.746	1.931	0.180	0.089
40	1.940	62.426	1071.0	3.229	1.664	0.248	0.122
50	1.940	62.409	1065.3	2.735	1.410	0.362	0.178
60	1.938	62.366	1059.7	2.359	1.217	0.522	0.256
70	1.936	62.301	1054.0	2.050	1.058	0.739	0.363
80	1.934	62.216	1048.4	1.799	0.930	1.032	0.507
90	1.931	62.113	1042.7	1.595	0.826	1.422	0.698
100	1.927	61.994	1037.1	1.424	0.739	1.933	0.950
120	1.918	61.713	1025.6	1.168	0.609	3.448	1.693
140	1.908	61.379	1014.0	0.981	0.514	5.884	2.890
160	1.896	61.000	1002.2	0.838	0.442	9.656	4.742
180	1.883	60.580	990.2	0.726	0.386	15.295	7.512
200	1.868	60.121	977.9	0.637	0.341	23.468	11.526
212	1.860	59.828	970.3	0.593	0.319	29.921	14.696

*To obtain values of viscosity, multiply values shown in table by 10^{-5}.

PROPERTIES OF WATER IN SI UNITS

Temp. (°C)	Density (kg/cm^3)	Specific Weight (kN/m^3)	Heat of Vaporization (cal/g)	Viscosity* Absolute (cP)	Viscosity* Kinematic (cSt)	Vapor Pressure (mm Hg)	Vapor Pressure (g/cm^2)
0	999.87	9.805	597.3	1.781	1.785	4.58	6.23
5	999.99	9.807	594.5	1.518	1.519	6.54	8.89
10	999.73	9.804	591.7	1.307	1.306	9.20	12.51
15	999.13	9.798	588.9	1.140	1.140	12.78	17.38
20	998.24	9.789	586.0	1.002	1.003	17.53	23.83
25	997.08	9.777	583.2	0.890	0.893	23.76	32.30
30	995.68	9.764	580.4	0.798	0.801	31.83	43.27
40	992.25	9.730	574.7	0.653	0.658	55.34	75.23
50	988.07	9.689	569.0	0.547	0.554	92.56	125.83
60	983.23	9.642	563.2	0.466	0.474	149.46	203.19
70	977.80	9.589	557.4	0.404	0.413	233.79	317.84
80	978.12	9.530	551.4	0.355	0.365	355.28	483.01
90	965.34	9.466	545.3	0.315	0.326	525.89	714.95
100	958.39	9.399	539.1	0.282	0.294	760.00	1033.23

*1 poise (P) = 0.10 N-s/m^2 $\therefore$ 1 centipoise (cP) = 1×10^{-3} N-s/m^2
1 stoke (St) = 1 cm^2/s $\therefore$ 1 centistoke (cSt) = 1×10^{-6} m^2/s

SCS 24-HR RAINFALL DISTRIBUTION (AT HALF-HOUR INCREMENTS)

Time (h)	Fraction of 24-hr Rainfall Depth: Type I	Type IA	Type II	Type III
0.0	0.00000	0.00000	0.00000	0.00000
0.5	0.00871	0.01000	0.00513	0.00500
1.0	0.01745	0.02000	0.01050	0.01000
1.5	0.02621	0.03500	0.01613	0.01500
2.0	0.03500	0.05000	0.02200	0.02000
2.5	0.04416	0.06600	0.02813	0.02519
3.0	0.05405	0.08200	0.03450	0.03075
3.5	0.06466	0.09800	0.04113	0.03669
4.0	0.07600	0.11600	0.04800	0.04300
4.5	0.08784	0.13500	0.05525	0.04969
5.0	0.09995	0.15600	0.06300	0.05675
5.5	0.11234	0.18000	0.07125	0.06419
6.0	0.12500	0.20600	0.08000	0.07200
6.5	0.13915	0.23700	0.08925	0.08063
7.0	0.15600	0.26800	0.09900	0.09050
7.5	0.17460	0.31000	0.10925	0.10163
8.0	0.19400	0.42500	0.12000	0.11400
8.5	0.21900	0.48000	0.13225	0.12844
9.0	0.25400	0.52000	0.14700	0.14575
9.5	0.30300	0.55000	0.16300	0.16594
10.0	0.51500	0.57700	0.18100	0.18900
10.5	0.58300	0.60100	0.20400	0.21650
11.0	0.62300	0.62400	0.23500	0.25000

SCS 24-HR RAINFALL DISTRIBUTION (AT HALF-HOUR INCREMENTS) (*Continued*)

Time (h)	Fraction of 24-hr Rainfall Depth			
	Type I	Type IA	Type II	Type III
11.5	0.65550	0.64500	0.28300	0.29800
12.0	0.68400	0.66400	0.66300	0.50000
12.5	0.70925	0.68300	0.73500	0.70200
13.0	0.73200	0.70100	0.77200	0.75000
13.5	0.75225	0.71900	0.79900	0.78350
14.0	0.77000	0.73600	0.82000	0.81100
14.5	0.78625	0.75281	0.83763	0.83406
15.0	0.80200	0.76924	0.85350	0.85425
15.5	0.81725	0.78529	0.86763	0.87156
16.0	0.83200	0.80096	0.88000	0.88600
16.5	0.84625	0.81625	0.89119	0.89838
17.0	0.86000	0.83116	0.90175	0.90950
17.5	0.87325	0.84569	0.91169	0.91938
18.0	0.88600	0.85984	0.92100	0.92800
18.5	0.89825	0.87361	0.92969	0.93581
19.0	0.91000	0.88700	0.93775	0.94325
19.5	0.92125	0.90001	0.94519	0.95031
20.0	0.94225	0.92489	0.95844	0.96336
20.5	0.94225	0.92489	0.95844	0.96336
21.0	0.95200	0.93676	0.96475	0.96944
21.5	0.96125	0.94825	0.97094	0.97523
22.0	0.97000	0.95936	0.97700	0.98075
22.5	0.97825	0.97009	0.98294	0.98598
23.0	0.98600	0.98044	0.98875	0.99094
23.5	0.99325	0.99041	0.99444	0.99561
24.0	1.00000	1.00000	1.00000	1.00000

CONVERSION FACTORS

Multiply	By	To Obtain
Acre-feet	1,233.49	cubic meters
Acre-feet	43,560	cubic feet
Acre-feet	0.0504	second-foot-day
Acre-feet	1,235	cubic yard
Acres	10	square chains
Acres	4,046.87	square meters
Acres	0.4047	hectares
Acres	1.562×10^{-3}	square miles
Acres	43,560.0	square feet
Angstrom units	3.937×10^{-9}	inches
Angstrom units	1×10^{-4}	microns
Atmosphere	101.325	kilopascals
Atmospheres	14.696	pounds/square inch
Atmospheres	76.0	centimeters of mercury
Atmospheres	33.8995	feet of water
Atmospheres	20.921	inches of mercury
BTU/hr	0.2931	watts
BTUs	2.928×10^{-4}	kilowatt-hours
BTUs	3.931×10^{-4}	horsepower-hours
Calories, gram (mean)	3.9685×10^{-3}	BTU (mean)
Centares	1.0	square meters
Centimeters	3.281×10^{-2}	feet
Centimeters	10.0	millimeters
Centimeters	0.3937	inches
Centimeters	1×10^{-2}	meters
Centimeters	1×10^{-5}	kilometers
Centimeters/second	0.03281	feet/second
Chain	22	yards
Chain	66	feet
Chain	4	rods
Chains	792.0	inches
Cubic centimeters	2.113×10^{-3}	pints (U.S. liquid)
Cubic centimeters	0.06102	cubic inches
Cubic feet/second	0.6463	million gallons/day
Cubic feet/minute	62.43	pounds water/minute
Cubic feet/second	448.831	gallons/minute

CONVERSION FACTORS (*Continued*)

Multiply	By	To Obtain
Cubic feet	0.02832	cubic meters
Cubic foot	7.48	U.S. gallon
Cubic feet/second	28.316	liter/second
Cubic inch	16.3870	cubic centimeters
Cubic meter	35.3147	cubic feet
Cubic meters/second	35.312	cubic feet/second
Cubic meters	1,000	liters
Cubic meters/second	15,800	gallons/minute
Cubic yard	27	cubic foot
Cubic yard	0.7646	cubic meter
Cubic yards	202.0	gallons
Day (mean solar)	86,400	seconds
Day (sidereal)	86,164.09	seconds
Degrees (angle)	0.0174533	radians
Degrees (angle)	17.7778	mile
Degrees/second	0.1667	revolutions/minute
Dynes	1.020×10^{-3}	grams
Dynes	1×10^{-5}	joules/meter (newtons)
Engineer's link	1	feet
Ergs	7.3670×10^{-8}	foot-pounds
Ergs	2.778×10^{-14}	kilowatt-hours
Ergs	9.480×10^{-11}	BTUs
Fathoms	6.0	feet
Fathoms	1.839	meters
Feet	0.3048	meters
Feet	1.645×10^{-4}	miles (nautical)
Feet	1.894×10^{-4}	miles (statute)
Feet	30.48	centimeters
Feet/minute	0.5080	centimeters/second
Feet/second	0.3048	meters/second
Feet/second	0.6818	miles/hour
Feet/second	0.5921	knots
Feet/second	30.48	centimeters/second
Foot-pounds	3.766×10^{-7}	kilowatt-hours
Foot-pounds	1.286×10^{-3}	BTUs
Foot-pounds	1.356	joules
Furlongs	660.0	feet
Furlongs	0.125	miles (statute)
Gallons/minute	2.227×10^{-3}	cubic feet/second
Gallons	3.785	liters
Gallons/minute	8.0208	cubic feet/hour
Gallons of water	8.3453	pounds of water
Grads	0.9	degrees (angle)
Grads	0.01570797	radians
Grams	3.527×10^{-2}	ounces (avoirdupois)
Grams	2.205×10^{-3}	pounds
Grams	3.215×10^{-2}	ounces (troy)
Hectares	10,000	square meters
Hectares	1.076×10^{5}	square feet
Hectares	2.471	acres
Horsepower	745.7	watts
Horsepower	0.7457	kilowatts
Horsepower	42.42	BTU/minute
Horsepower	550	foot-pounds/second
Hours	5.952×10^{-3}	weeks
Hours	4.167×10^{-2}	days
Inches	25.4	millimeters
Inches	1.578×10^{-5}	miles
Inches	2.540	centimeters
Joules	9.480×10^{-4}	BTUs
Joules	1×10^{7}	ergs
Kilograms	2.205	pounds (avoirdupois)
Kilometers	1,000.0	meters
Kilometers	3,281.0	feet
Kilometers	0.6214	miles
Kilometers/hour	0.5396	knots
Kilowatt-hours	3,413.0	BTUs
Kilowatts	1.341	horsepower
Knots	1.852	kilometers/hour
Knots	0.5144	meters/second
Knots	1.0	nautical miles/hour
Knots	1.151	statute miles/hour
Knots	6.080.0	feet/hour
Labors	177.14	acres
Leagues	4,428.40	meters
Links (gunters)	66	feet
Links (surveyor's)	7.92	inches
Liters	61.02	cubic inches
Liters	0.2642	gallons (U.S. liquid)
Liters	1,000.0	milliliters
Liters	2.113	pints (U.S. liquid)
Liters	1,000.0	cubic centimeters
Liters/minute	5.886×10^{-4}	cubic feet/second
Liters/second	15.85	gallons/day
Meters	5.396×10^{-4}	miles (nautical)
Meters	100.0	centimeters
Meters	6.214×10^{-4}	miles (statute)
Meters	1×10^{-3}	kilometers
Meters	3.281	feet
Meters	1,000.0	millimeters
Micrometers	1×10^{-6}	meters
Miles (nautical)	6,080.27	feet
Miles (nautical)	1.853	kilometers
Miles (nautical)	1.1516	miles (statute)
Miles (statute)	0.8684	miles (nautical)
Miles (statute)	1.609	kilometers
Miles (statute)	320	rods
Miles (statute)	5,280	feet
Miles (statute)	80	chains (surveyor's)
Miles/hour	88.0	feet/minute
Millibar	0.01^{43}	pounds/square inch
Milligram/liter	1.0	parts per million
Milligrams/liter	8.345	pounds/million gallons
Milliliters	1×10^{-3}	liters
Millimeters	3.937×10^{-2}	inches
Mils	3,037,500	minutes
Mils	0.05625	degrees (angle)
Minutes (angle)	0.29630	mils
Minutes (angle)	0.000290888	radians
Minutes (mean solar)	60	seconds

CONVERSION FACTORS (*Continued*)

MULTIPLY	BY	TO OBTAIN	MULTIPLY	BY	TO OBTAIN
Minutes (sidereal)	59.83617	seconds	Revolutions/minute	6.0	degrees/second
Newtons	1×10^5	dynes	Rods	1	poles
Newtons/square meter	1	pascals	Rods	16.5	feet
Ounces	6.25×10^{-2}	pounds	Rods	5.029	meters
Ounces	28.349527	grams	Rods	1	perches
Ounces (troy)	1.09714	ounces (avoirdupois)	Rods (surveyor's measure)	5.5	yards
Outs	10	33-foot chains	Seconds	1.667×10^{-2}	minutes
Outs	330	feet	Seconds (angle)	4.848137×10^{-6}	radians
Pints (liquid)	0.125	gallons	Seconds (sidereal)	0.9972696	seconds (mean solar)
Pints (liquid)	28.87	cubic inches	Slug/cubic foot	515.4	kilograms/cubic meter
Pints (liquid)	473.2	cubic centimeters	Slugs	32.17	pounds
Pints (liquid)	0.5	quarts (liquid)	Square miles	640	acres
Pounds	0.4536	kilograms	Square miles	27,878,400	square feet
Pounds	14.5833	ounces (troy)	Square meters	10.76	square feet
Pounds	1.21528	pounds (troy)	Surveyor's link	7.92	inches
Pounds	16.0	ounces	Surveyor's link	0.66	feet
Pounds/cubic foot	16.02	kilograms/cubic meter	Tons (long)	1.120	tons (short)
Pounds (force)	4.4482	newtons	Tons (long)	2,240.0	pounds
Pounds (mass)	0.4536	kilograms	Tons (long)	1,016.0	kilograms
Pounds/square inch	6.895	kilo Newton/square meter	Tons (metric)	2,205	pounds
Pounds/square inch	6.895	newtons/square meter	Tons (short)	907.1848	kilograms
Pounds/square foot	47.880	pascals	Tons (short)	0.89287	tons (long)
Quarts (dry)	67.20	cubic inches	Tons (short)	2,000.0	pounds
Quarts (liquid)	57.75	cubic inches	VARA (California)	33	inches
Quarts (liquid)	0.9463	liters	VARA (Texas)	33.333	inches
Quarts (liquid)	0.25	gallons	Watts	1.341×10^{-3}	horsepower
Radians	3,438.0	minutes	Watts	1.0	joules/second
Radians	57°17′44.806″	degrees (angle)	Watts	3.4129	BTU/hour
Radians	57.2957795	degrees (angle)	Yards	5.682×10^{-4}	miles (statute)
Radians/second	9.549	revolutions/minute	Yards	4.934×10^{-4}	miles (nautical)
Revolutions	360.0	degrees	Yards	0.9144	meters

RELATIONSHIP BETWEEN TEMPERATURES

$°F = 32 + (9/5)°C$		$°C = 5/9(°F - 32)$	
°F	**°C**	**°C**	**°F**
–20	–28.9	–20	–4
0	–17.8	–10	14
20	–6.7	0	32
32	0.0	10	50
40	4.5	20	68
60	15.5	30	86
80	26.6	40	104
100	37.8	50	122
120	48.9	0	140
140	60.0	70	158
160	71.1	80	176
180	82.2	90	194
212	100.0	100	212

°Rankine (°F Absolute) = °F + 459.58
°Kelvin (°C Absolute) = °C + 273.1

PREFIXES FOR USE WITH SI SYSTEM

MULTIPLE	PREFIX	SYMBOL
10^{12}	tera	
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	
10	deka	
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-12}	nano	n
10^{-15}	pico	p

PHYSICAL PROPERTIES OF SELECTED MATERIALS

MATERIAL	UNIT WEIGHT LB/FT^3	SPECIFIC GRAVITY*	MELTING POINT °F	BOILING POINT °F	SPECIFIC HEAT (CONSTANT PRESSURE FOR GASES)
Acetylene	0.0732	0.00117	–114.7	–118.5	0.383
Air	0.0802	0.00129	—	—	0.238
Alcohol:					
ethyl	49	0.789	–176	173	0.55
methyl	49	0.792	–144	148.4	0.60
Aluminum (pure)	168	2.702	1220	3270–4530	0.226
Ammonia	0.0481	0.00077 1	–108	–28	0.520
Antimony	417	6.684	1167	2620	0.049
Argon	0.1114	0.00178	–308.6	–302.3	0.123
Asbestos	125–175	2.0–2.8	—	—	0.195
Asphalt	56–106	0.9–1.7	—	—	—
Basalt	150–200	2.4–3.2	—	—	0.20–0.24
Bauxite	159	2.55	—	—	—
Benzene	55	0.879	42	176.2	0.42
Bismuth	611	9.80	520	2590–2840	0.034
Borax	106–112	1.7–1.8	—	—	—
Brass:					
low (80 Cu,20 Zn)	541	8.66	1830	—	—
Red (85 Cu, 15Zn)	546	8.75	1880	—	—
Yellow (65 Cu, 35 Zn)	529	8.49	1710	—	—
Brick:					
common	112	1.8	—	—	—
fire	145	2.3	—	—	—
Bronze, comm. 90 Cu, 10 Zn)	549	8.80	1910	—	—
Butane:					
iso-	0.165	0.00264	–240	12	—
n	0.158	0.00252	–213	31	—
Cadmium	539	8.64	610	1410	0.055
Calcite	168	2.7	—	—	—
Calcium	97	1.55	1550	2200	0.149
Carbon:					
diamond	219	3.51	6700	7600	0.12
graphite	141	2.25	6700	7600	0.165
Carbon dioxide	0.1234	0.00198	–70.6	–112	0.20
Carbon monoxide	0.0781	0.00125	–340.6	–312.7	0.25
Cement, Portland:					
loose	94	1.51	—	—	—
solid	197	3.15	—	—	—
Chalk	119–175	1.9–2.8	—	—	0.214
Chlorine	0.2006	0.00321	–155	–30	0.113
Chromium	448	7.19	3430	4000	0.11
Coal:					
anthracite	87–112	1.4–1.8	—	—	—
bituminous	75–100	1.2–1.6	—	—	—
Cobalt	555	8.9	2700	5250	0.099

PHYSICAL PROPERTIES OF SELECTED MATERIALS (*Continued*)

MATERIAL	UNIT WEIGHT LB/FT^3	SPECIFIC GRAVITY*	MELTING POINT °F	BOILING POINT °F	SPECIFIC HEAT (CONSTANT PRESSURE FOR GASES)
Concrete	144–150	2.3–2.4	—	—	0.156
Copper	556	8.92	1980	4700	0.092
Dolomite	177	2.84	—	—	—
Earth:					
dry, loose	75	1.2	—	—	—
dry, packed	95	1.5	—	—	—
moist, loose	80	1.3	—	—	—
moist, packed	100	1.6	—	—	—
mud, flowing	105	1.7	—	—	—
mud, packed	110	1.8	—	—	—
Feldspar	160–170	2.56–2.73	—	—	—
Flint	164	2.63	—	—	—
Fluorine	0.1059	0.00169	–365	–305	0.182
Gasoline	41–47	0.66–0.75	—	160–190	0.500
Glass	153–172	2.45–2.75	—	—	0.16–0.20
Glycerin	78	1.26	64.6	554	0.576
Gneiss	150–170	2.4–2.7	—	—	0.18
Granite	165–170	2.65–2.7	—	—	0.192
Gravel:					
dry, loose	85–105	2.5–2.7	—	—	—
dry, packed	100–120	2.5–2.7	—	—	—
Gypsum	145	2.33	—	—	0.259
Helium	0.0111	0.000178	–458	–452	1.25
Hydrogen	0.0056	0.000090	–434	–423	3.39
Ice	55–57	0.88–0.92	—	—	—
Iridium	1400	22.42	4450	9600	0.032
Iron	490	7.86	2800	5430	0.11
Ivory	114–120	1.83–1.92	—	—	—
Lead	708	11.34	621.3	2950	0.031
Leather	54–64	0.86–1.02	—	—	—
Limestone	130–180	2.1–2.86	—	—	—
Linseed oil	58	0.934	–4	550	—
Magnesium	109	1.74	1200	2030	0.249
Manganese	450	72	2300	3900	0.115
Marble	160–180	2.6–2.86	—	—	0.21
Mercury	845	13.55	–38.0	673	0.033
Methane	0.0448	0.000717	–300	–258.5	0.593
Mica	165–200	2.7–3.1	—	—	0.21
Molybdenum	636	10.2	4750	6690	0.06
Neon	0.0562	0.000900	–415.6	–410.6	—
Nickel	555	8.9	2650	5250	0.11
Nitrogen	0.0781	0.00125	–345.75	–320.4	0.244
Osmium	1405	22.48	4400	9900	0.031
Oxygen	0.0892	0.001429	–361.1	–297.4	0.218
Paper	44–72	0.7–1.15	—	—	—
Petroleum	54	0.87	—	—	0.50

PHYSICAL PROPERTIES OF SELECTED MATERIALS (*Continued*)

MATERIAL	UNIT WEIGHT LB/FT^3	SPECIFIC GRAVITY*	MELTING POINT °F	BOILING POINT °F	SPECIFIC HEAT (CONSTANT PRESSURE FOR GASES)
Porcelain	143–156	2.3–2.5	—	—	0.26
Propane	0.1261	0.00201	–310	–44	—
Pumice	23–56	0.37–0.90	—	—	—
Quartz	160–170	2.6–2.7	—	—	0.17
Salt	49–78	0.78–1.25	—	—	—
Sand:					
dry	90–110	2.4–2.7	—	—	—
wet	118–129	2.4–2.7	—	—	—
Slate	160–205	2.6–3.3	—	—	—
Sulfur	129	2.07	246	832	0.18
Tar, bituminous	64	1.02	—	—	—
Tin	456	7.3	449	4100	0.055
Titanium	281	4.5	3270	>5400	0.126
Tungsten	1204	19.3	6120	10.650	0.032
Turpentine	54	0.873	14	320	0.411
Vanadium	372	5.96	3110	5430	0.12
Water:					
fresh	62.43	1.00000	32	212	1.000
sea	63.5–64.2	1.02–1.03	—	—	—
Zinc	445	7.14	787	1665	0.093

*Specific gravity measured at 32°F and 1 atmosphere.

2005 MINIMUM STANDARD DETAIL REQUIREMENTS FOR ALTA/ACSM LAND TITLE SURVEYS as adopted by American Land Title Association and National Society of Professional Surveyors

(a member organization of the American Congress on Surveying and Mapping)

It is recognized that members of the American Land Title Association (ALTA) have specific needs, peculiar to title insurance matters, which require particular information for acceptance by title insurance companies when said companies are asked to insure title to land without exception as to the many matters which might be discoverable from survey and inspection and not be evidenced by the public records. In the general interest of the public, the surveying profession, title insurers and abstracters, ALTA and the National Society of Professional Surveyors, Inc. (NSPS) jointly promulgate and set forth such details and criteria for standards. It is recognized and understood that local and state standards or standards of care, which surveyors in those respective jurisdictions are bound by, may augment, or even require variations to the standards outlined herein. Where conflicts between the standards outlined herein and any jurisdictional statutes or regulations occur, the more restrictive requirement shall apply. It is also recognized that title insurance companies are entitled to rely on the survey furnished to them to be of an appropriate professional quality, both as to completeness and as to accuracy. It is equally recognized that for the performance of a survey, the surveyor will be provided with appropriate data which can be relied upon in the preparation of the survey.

For a survey of real property and the plat or map of the survey to be acceptable to a title insurance company for purposes of insuring title to said real property free and clear of survey matters (except those matters disclosed by the survey and indicated on the plat or map), certain specific and pertinent information shall be presented for the distinct and clear understanding between the client (insured), the title insurance company (insurer), and the surveyor (the person professionally responsible for the survey). These requirements are:

1. The client shall request the survey or arrange for the survey to be requested and shall provide a written authorization to proceed with the survey from the person responsible for paying for the survey. Unless specifically authorized in writing by the insurer, the insurer shall not be responsible for any costs associated with the preparation of the survey. The request shall specify that an "**ALTA/ACSM LAND TITLE SURVEY**" is required and shall designate which of the optional items listed in Table A are to be incorporated. The request shall set forth the record description of the property to be surveyed or, in the case of an original survey, the record description of the parent parcel that contains the property to be surveyed. Complete copies of the record description of the property (or, in the case of an original survey, the parent parcel), any record easements benefiting the property; the record easements or servitudes and covenants burdening the property ("Record Documents"); documents of record referred to in the Record Documents; and any other documents containing desired appropriate information affecting the property being surveyed and to which the survey shall make reference shall be provided to the surveyor for notation on the plat or map of survey.

2. The plat or map of such survey shall bear the name, address, telephone number, and signature of the professional land surveyor who performed the survey, his or her official seal and registration number, the date the survey was completed, the dates of all of the surveyor's revisions and the caption "ALTA/ACSM Land Title Survey" with the certification set forth in paragraph 8.

3. An "**ALTA/ACSM LAND TITLE SURVEY**" shall be in accordance with the then-current "Accuracy Standards for Land Title Surveys" ("Accuracy Standards") as adopted, from time to time by the National Society of Professional Surveyors and the American Land Title Association and incorporated herein by reference.

4. On the plat or map of an "**ALTA/ACSM LAND TITLE SURVEY,**" the survey boundary shall be drawn to a convenient scale, with that scale clearly indicated. A graphic scale, shown in feet or meters or both, shall be included. A north arrow shall be shown and when practicable, the plat or map of survey shall be oriented so that north is at the top of the drawing. Symbols or abbreviations used shall be identified on the face of the plat or map by use of a legend or other means. If necessary for clarity, supplementary or exaggerated diagrams shall be presented accurately on the plat or map. The plat or map shall be a minimum size of 8½ by 11 inches.

5. The survey shall be performed on the ground and the plat or map of an "**ALTA/ACSM LAND TITLE SURVEY**" shall contain, in addition to the required items already specified above, the following applicable information:

(a) All data necessary to indicate the mathematical dimensions and relationships of the boundary represented, with angles given directly or by bearings, and with the length and radius of each curve, together with elements necessary to mathematically define each curve. The point of beginning of the surveyor's description shall be shown as well as the remote point of beginning if different. A bearing base shall refer to some well-fixed line, so that the bearings may be easily re-established. The North arrow shall be referenced to its bearing base and should that bearing base differ from record title, that difference shall be noted.

(b) When record bearings or angles or distances differ from measured bearings, angles, or distances, both the record and measured bearings, angles, and distances shall be clearly indicated. If the record description fails to form a mathematically closed figure, the surveyor shall so indicate.

(c) Measured and recorded distances from corners of parcels surveyed to the nearest right-of-way lines of streets in urban or suburban areas, together with recovered lot corners and evidence of lot corners, shall be noted. For streets and highways abutting the property surveyed, the name, the width and location of pavement relative to the nearest boundary line of the surveyed tract, and the width of existing rights of way, where available from the controlling jurisdiction, shall be shown. Observable evidence of access (or lack thereof) to such abutting streets or highways shall be indicated. Observable evidence of private roads shall be so indicated. Streets abutting the premises, which have been described in Record Documents, but not physically opened, shall be shown and so noted.

(d) The identifying titles of all recorded plats, filed maps, right of way maps, or similar documents which the survey represents, wholly or in part, shall be shown with their appropriate recording data, filing dates and map numbers, and the lot, block, and section numbers or letters of the surveyed premises. For non-platted adjoining land, names, and recording data identifying adjoining owners as they appear of record shall be shown. For platted adjoining land, the recording data of the subdivision plat shall be shown. The survey shall indicate platted setback or building restriction lines which have been recorded in subdivision plats or which appear in Record Documents which have been delivered to the surveyor. Contiguity, gores, and overlaps along the exterior boundaries of the surveyed premises, where ascertainable from field evidence or Record Documents, or interior to those exterior boundaries, shall be clearly indicated or noted. Where only a part of a recorded lot or parcel is included in the survey, the balance of the lot or parcel shall be indicated.

(e) All evidence of monuments shall be shown and noted to indicate which were found and which were placed. All evidence of monuments found beyond the surveyed premises on which establishment of the corners of the surveyed premises are dependent, and their application related to the survey shall be indicated.

(f) The character of any and all evidence of possession shall be stated and the location of such evidence carefully given in relation to both the measured boundary lines and those established by the record. An absence of notation on the survey shall be presumptive of no observable evidence of possession.

(g) The location of all buildings upon the plot or parcel shall be shown and their locations defined by measurements perpendicular to the nearest perimeter boundaries. The precision of these measurements shall be commensurate with the Relative Positional Accuracy of the survey as specified in the current Accuracy Standards for ALTA/ACSM Land Title Surveys. If there are no buildings erected on the property being surveyed, the plat or map shall bear the statement, "No buildings." Proper street numbers shall be shown where available.

(h) All easements evidenced by Record Documents which have been delivered to the surveyor shall be shown, both those burdening and those benefiting the property surveyed, indicating recording information. If such an easement cannot be located, a note to this effect shall be included. Observable evidence of easements and/or servitudes of all kinds, such as those created by roads; rights-of-way; water courses; drains; telephone, telegraph, or electric lines; water, sewer, oil or gas pipelines on or across the surveyed property and on adjoining properties if they appear to affect the surveyed property, shall be located and noted. If the surveyor has knowledge of any such easements and/or servitudes, not observable at the time the present survey is made, such lack of observable evidence shall be noted. Surface indications, if any, of underground easements and/or servitudes shall also be shown.

(i) The character and location of all walls, buildings, fences, and other visible improvements within five feet of each side of the boundary lines shall be noted. Without expressing a legal opinion, physical evidence of all encroaching structural appurtenances and projections, such as fire escapes, bay windows, windows and doors that open out, flue pipes, stoops, eaves, cornices, areaways, steps, trim, etc., by or on adjoining property or on abutting streets, on any easement or over setback lines shown by Record Documents shall be indicated with the extent of such encroachment or projection. If the client wishes to have additional information with regard to appurtenances such as whether or not such appurtenances are independent, division, or party walls and are plumb, the client will assume the responsibility of obtaining such permissions as are necessary for the surveyor to enter upon the properties to make such determinations.

(j) Driveways, alleys and other ways of access on or crossing the property must be shown. Where there is evidence of use by other than the occupants of the property, the surveyor must so indicate on the plat or map. Where driveways or alleys on adjoining properties encroach, in whole or in part, on the property being surveyed, the surveyor must so indicate on the plat or map with appropriate measurements.

(k) As accurately as the evidence permits, the location of cemeteries and burial grounds (i) disclosed in the Record Documents provided by client or (ii) observed in the process of performing the field work for the survey, shall be shown.

(l) Ponds, lakes, springs, or rivers bordering on or running through the premises being surveyed shall be shown.

6. As a minimum requirement, the surveyor shall furnish two sets of prints of the plat or map of survey to the title insurance company or the client. If the plat or map of survey consists of more than one sheet, the sheets shall be numbered, the total number of sheets indicated and match lines be shown on each sheet. The prints shall be on durable and dimensionally stable material of a quality standard acceptable to the title insurance company. The record title description of the surveyed tract, or the description provided by the client, and any new description prepared by the surveyor must appear on the face of the plat or map or otherwise accompany the survey. When, in the opinion of the surveyor, the results of the survey differ significantly from the record, or if a fundamental decision related to the boundary resolution is not clearly reflected on the plat or map, the surveyor may explain this information with notes on the face of the plat or map or in accompanying attachments. If the relative positional accuracy of the survey exceeds that allowable, the surveyor shall explain the site conditions that resulted in that outcome with a note on the face of the map or plat.

7. Water boundaries necessarily are subject to change due to erosion or accretion by tidal action or the flow of rivers and streams. A realignment of water bodies may also occur due to many reasons such as deliberate cutting and filling of bordering lands or by avulsion. Recorded surveys of natural water boundaries are not relied upon by title insurers for location of title.

When a property to be surveyed for title insurance purposes contains a natural water boundary, the surveyor shall measure the location of the boundary according to appropriate surveying methods and note on the plat or map the date of the measurement and the caveat that the boundary is subject to change due to natural causes and that it may or may not represent the actual location of the limit of title. When the surveyor is aware of changes in such boundaries, the extent of those changes shall be identified.

8. When the surveyor has met all of the minimum standard detail requirements for an ALTA/ACSM Land Title Survey, the following certification shall be made on the plat:

To (name of client), (name of lender, if known), (name of title insurance company, if known), (name of others as instructed by client):

This is to certify that this map or plat and the survey on which it is based were made in accordance with the "Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys," jointly established and adopted by ALTA and NSPS in 2005, and includes items ____ of Table A thereof. Pursuant to the Accuracy Standards as adopted by ALTA and NSPS and in effect on the date of this certification, undersigned further certifies that in my professional opinion, as a land surveyor registered in the State of __________, the Relative Positional Accuracy of this survey does not exceed that which is specified therein.

Date: (signed) (seal)
Registration No.

NOTE: If, as otherwise allowed in the Accuracy Standards, the Relative Positional Accuracy exceeds that which is specified therein, the following certification shall be made on the plat:

To (name of client), (name of lender, if known), (name of title insurance company, if known), (name of others as instructed by client):

This is to certify that this map or plat and the survey on which it is based were made in accordance with the "Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys," jointly established and adopted by ALTA and NSPS in 2005, and includes items ____ of Table A thereof. Pursuant to the Accuracy Standards as adopted by ALTA and NSPS and in effect on the date of this certification, undersigned further certifies that in my professional opinion, as a land surveyor registered in the State of __________, the maximum Relative Positional Accuracy is ____ feet.

Date: (signed) (seal)
Registration No.

The 2005 Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys are effective January 1, 2006. As of that date, all previous versions of the Minimum Standard Detail Requirements for ALTA/ACSM Land Title Surveys are superseded by these 2005 standards.

Adopted by the American Land Title Association on October 5, 2005.
Adopted by the Board of Directors, National Society of Professional Surveyors on October 24, 2005.
American Land Title Association, 1828 L St., N.W., Suite 705, Washington, D.C. 20036.
National Society of Professional Surveyors, Inc., 6 Montgomery Village Avenue, Suite 403, Gaithersburg, MD 20879

TABLE A

OPTIONAL SURVEY RESPONSIBILITIES AND SPECIFICATIONS

NOTE: The items of Table A must be negotiated between the surveyor and client. It may be necessary for the surveyor to qualify or expand upon the description of these items, e.g., in reference to Item 6, there may be a need for an interpretation of a restriction. The surveyor cannot make a certification on the basis of an interpretation or opinion of another party. Items 16, 17 and 18 are only for use on projects for the U.S. Department of Housing and Urban Development (HUD).

If checked, the following optional items are to be included in the ALTA/ACSM LAND TITLE SURVEY, except as otherwise negotiated:

1. ____ *Monuments placed (or a reference monument or witness to the corner) at all major corners of the boundary of the property, unless already marked or referenced by an existing monument or witness to the corner.*

2. ____ *Vicinity map showing the property surveyed in reference to nearby highway(s) or major street intersection(s).*

3. ____ *Flood zone designation (with proper annotation based on federal Flood Insurance Rate Maps or the state or local equivalent, by scaled map location and graphic plotting only.)*

4. ____ *Gross land area (and other areas if specified by the client).*

5. ____ *Contours and the datum of the elevations.*

6. ____ *List setback, height, and floor space area restrictions disclosed by applicable zoning or building codes (beyond those required under paragraph 5d of these standards). If none, so state. The source of such information must be disclosed. See "Note" above.*

7. ____ *(a) Exterior dimensions of all buildings at ground level*

   (b) Square footage of:

   ____ *(1) exterior footprint of all buildings at ground level*

   ____ *(2) gross floor area of all buildings; or*

   ____ *(3) other areas to be defined by the client*

   ____ *(c) Measured height of all buildings above grade at a defined location. If no defined location is provided, the point of measurement shall be shown.*

8. ____ *Substantial, visible improvements (in addition to buildings) such as billboards, signs, parking structures, swimming pools, etc.*

9. ____ *Parking areas and, if striped, the striping and the type (e.g. handicapped, motorcycle, regular, etc.) and number of parking spaces.*

10. ____ *Indication of access to a public way on land such as curb cuts and driveways, and to and from waters adjoining the surveyed tract, such as boat slips, launches, piers and docks*

11. *Location of utilities (representative examples of which are shown below) existing on or serving the surveyed property as determined by:*

   ____ *(a) Observed evidence*

   ____ *(b) Observed evidence together with evidence from plans obtained from utility companies or provided by client, and markings by utility companies and other appropriate sources (with reference as to the source of information)*

   - railroad tracks and sidings;
   - manholes, catch basins, valve vaults or other surface indications of subterranean uses;
   - wires and cables (including their function, if readily identifiable) crossing the surveyed premises, all poles on or within ten feet of the surveyed premises, and the dimensions of all crossmembers or overhangs affecting the surveyed premises; and
   - utility company installations on the surveyed premises.

12. ____ *Governmental Agency survey-related requirements as specified by the client.*

13. ____ *Names of adjoining owners of platted lands.*

14. ____ *The distance to the nearest intersecting street as designated by the client*

15. ____ *Rectified orthophotography, photogrammetric mapping, laser scanning and other similar products, tools or technologies may be utilized as the basis for the location of certain features (excluding boundaries) where ground measurements are not otherwise necessary to locate those features to an appropriate and acceptable accuracy relative to a nearby boundary. The surveyor shall (a) discuss the ramifications of such methodologies (e.g., the potential accuracy and completeness of the data gathered thereby) with the title company, lender and client prior to the performance of the survey and (b) place a note on the face of the survey explaining the source, date, relative accuracy and other relevant qualifications of any such data.*

16. ____ *Observable evidence of earth moving work, building construction or building additions within recent months.*

17. ____ *Any changes in street right of way lines either completed or proposed, and available from the controlling jurisdiction. Observable evidence of recent street or sidewalk construction or repairs.*

18. ____ *Observable evidence of site use as a solid waste dump, sump or sanitary landfill.*

19. ____

Accuracy Standards for ALTA/ACSM Land Title Surveys

Introduction

These Accuracy Standards address Relative Positional Accuracies for measurements that control land boundaries on ALTA/ACSM Land Title Surveys.

In order to meet these standards, the surveyor must assure and certify that the Relative Positional Accuracies resulting from the measurements made on the survey do not exceed that which is allowable.

If the size or configuration of the property to be surveyed, or the relief, vegetation or improvements on the property will result in survey measurements for which the allowable Relative Positional Accuracies will be exceeded, the surveyor must alternatively certify as to the Relative Positional Accuracy that was otherwise achieved on the survey.

Definition:

"Relative Positional Accuracy" means the value expressed in feet or meters that represents the uncertainty due to random errors in measurements in the location of any point on a survey relative to any other point on the same survey at the 95 percent confidence level.

Background

The lines and corners on any property survey have uncertainty in location which is the result of (1) availability and condition of reference monuments, (2) occupation or possession lines as they may differ from record lines, (3) clarity or ambiguity of the record descriptions or plats of the surveyed tracts and its adjoiners and (4) Relative Positional Accuracy.

The first three sources of uncertainty must be weighed as evidence in the determination of where, in the professional surveyor's opinion, the boundary lines and corners should be placed. Relative Positional Accuracy is related to how accurately the surveyor is able to monument or report those positions.

Of these four sources of uncertainty, only Relative Positional Accuracy is controllable, although due to the inherent error in any measurement, it cannot be eliminated. The first three can be estimated based on evidence; Relative Positional Accuracy can be estimated using statistical means.

The surveyor shall, to the extent necessary to achieve the standard contained herein, (1) compensate or correct for systematic errors, including those associated with instrument calibration, (2) select the appropriate equipment and methods, and use trained personnel and (3) use appropriate error propagation and other measurement design theory to select the proper instruments, field procedures, geometric layouts and computational procedures to control random errors.

If radial survey methods, GPS or other acceptable technologies or procedures are used to locate or establish points on the survey, the surveyor shall apply appropriate procedures in order to assure that the allowable Relative Positional Accuracy of such points is not exceeded.

Computation of Relative Positional Accuracy

Relative Positional Accuracy may be tested by:
(1) comparing the relative location of points in a survey as measured by an independent survey of higher accuracy or
(2) the results of a minimally constrained, correctly weighted least square adjustment of the survey.

Allowable Relative Positional Accuracy for Measurements Controlling Land Boundaries on ALTA/ACSM Land Title Surveys

0.07 feet (or 20 mm) + 50 ppm

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE

Type	Program	Developed by	Available from	Comments
Coastal Models:				
Coastal Storm Surges	FEMA Surge (1988)	Tetra Tech, Inc.; Engineering Methods & Applications; Greenhome & O'Mara; Camp, Dresser & McKee, Inc.	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	Incorporates modified NWS-23 model for hurricanes and Joint Probability Method. Reportedly more accurate for water elevations than water currents. Public Domain: Yes
	Advanced Circulation Model (ADCIRC) 2DDI (2003)	Johannes Westerink, University of Notre Dame, and Rick Luettich, University of North Carolina at Chapel Hill, Institute of Marine Sciences for USACE Coastal and Hydraulics Laboratory	Nick Krauss, Coastal and Hydraulics Laboratory, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199. Also can be purchased from software vendors as a component of SWM.	Finite elements 2-D hydrodynamic model; the version 2DDI is vertically integrated continuity equation for water surface elevation; no storm or hurricane wind field models or statistical analysis tools are included with model, they must be acquired separately; ADCIRC performs well using Vince Cardone's planetary-boundary layer model windfields; statistical analyses using ADCIRC model storm surge simulations are compatible with the USACE Empirical Simulation Technique (EST) as well as joint probability methods. Public Domain: Yes, for flood insurance study purposes.
	TABS RMA2 v. 4.3 (Oct. 1996)	U.S. Army Corps of Engineers	Coastal Engineering Research Center Department of the Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road, Vicksburg, MS 39180-6199	Two-dimensional steady/unsteady flow model for water levels and velocities. Computes finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Public Domain: Yes
	MIKE 21 (HD/NHD) 2002 D, 2004, 2005, and 2007	DHI Water and Environment	DHI Inc., 319 SW Washington St., Suite 614, Portland, OR 97204	Solves the nonlinear depth-averaged equations of continuity and conservation of momentum. Computes water levels and flows based on a variety of forcing functions. Computes wave-driven currents and wave setup. Uses a finite difference grid with dynamic nesting grid capabilities. Resolving small-scale features such as narrow inland channels, culverts, and control structures can be accomplished using the DHI MIKE FLOOI

				interface, which allows for dynamic coupling between MIKE 21 and the DHI MIKE 11 model. Public Domain: No
	DYNLET	U.S. Army Corps of Engineers	Coastal and Hydraulics Laboratory Engineering Research and Development Center 3909 Halls Ferry Road Vicksburg, MS 39180-6199	One-dimensional model of dynamic behavior of tidal flow at inlets. Can be used to predict tide-dominated velocities and water-level fluctuations at an inlet and interior back bay system. DYNLET solves the full one-dimensional shallow water equations using an implicit finite difference solution. Public Domain: Yes
Coastal Wave Heights	WHAFIS 3.0 (1988)	Dames & Moore, revised by Greenhorne & O'Mara Dewberry	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	Defines wave heights associated with 100-year flood in coastal areas using modern wave action treatment; incorporates 1977 NAS recommendations on basic approximations for wind speeds, wave breaking criterion, and controlling wave height. Public Domain: Yes
	WHAFIS 3.0 GL (1993)	Dames & Moore, revised by Greenhorne & O'Mara	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	Identical wave treatments as WHAFIS 3.0, but with programmed reduction of wind speeds for U.S. shorelines of the Great Lakes. Public Domain: Yes
	RCPWAVE (1986)	U.S. Army Corps of Engineers	Coastal Engineering Research Center Department of Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Treats linear, monochromatic waves propagating over grid giving coastal bathymetry, providing near-shore wave heights pertinent to proper spacing between transects or to magnitudes of wave setup. Public Domain: Yes
	CHAMP 1.1 (2002) and 1.2 (2005)	Dewberry	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	Coastal Hazard Analysis Modeling Program (CHAMP) is a Windows-based program used for wave height analyses (enhanced WHAFIS 3.0) and provides summary tables and graphics for mapping. Public Domain: Yes

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Coastal Models (*Continued*):				
	MIKE 21 Flexible Mesh Spectral Wave Model (FM SW) 2004, 2005, and 2007	DHI Water and Environment	DHI Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Two-dimensional, flexible mesh, finite-volume, dynamic wind-wave growth and near-shore transformation model. The model includes a fully spectral formulation and a directional decoupled parametric formulation, includes wave-current interaction, and includes near-shore effects of refraction, shoaling, breaking, bed friction, and wind-wave growth. The wave model can be dynamically coupled with the MIKE 21 flexible Mesh Hydrodynamic (FM HD) model so that wave setup is computed directly by the HD model. Public Domain: Yes
	MIKE 21 Nearshore Spectral Wave Model (NSW) 2002D, 2005, and 2007	DHI Water and Environment	DHI Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Two-dimensional stationary model for propagation of waves into the near-shore zone (refraction, shoaling, breaking, bed friction, and wind-wave growth). Based on the conservation equation for the spectral wave action density; similar to HISWA mode. Obstructions not directly resolvable in the grid, must be modeled with grid bed roughness coefficients. Public Domain: Yes
Coastal Wave Effects	RUNUP 2.0 (1990)	Stone & Webster Engineering Corp., revised by Dewberry	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	Executes 1978 guidance by USACE defining wave runup on shore barrier with specified approach and storm conditions; mean wave description determines mean runup elevation. Public Domain: Yes
	ACES 1.07 (1992)	U.S. Army Corps of Engineers	Coastal Engineering Research Center Department of the Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Used for restricted fetch wave growth analysis and runup on vertical structures or revetments. Public Domain: Yes

	CHAMP 1.1 (2002) and 1.2 (2005)	Dewberry	The Mod Team 3601 Eisenhower Avenue Alexandria, VA 22304	CHAMP is a Windows-based program used for storm-induced erosion treatments (enhanced EROSION) and wave runup analyses (enhanced RUNUP 2.0), and provides summary tables and graphics for mapping. Public Domain: Yes
Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis				
One-Dimensional Steady Flow Models	HEC-RAS 3.1.1 and up	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	For water surface elevation difference due to use of different HEC-RAS versions, refer to FEMA Memorandum HEC-RAS Version Updates (August 17, 2004) Public Domain: Yes
	HEC-2 4.6.2 (May 1991)	US Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Includes culvert analysis and floodway options. Public Domain: Yes
	WSPRO (Jun. 1988 and up)	U.S. Geological Survey, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA)	Floodway option is available in June 1998 version. 1988 version is available on the U.S. Geological Survey website. Public Domain: Yes
	QUICK-2 1.0 and up (Jan. 1995)	FEMA	Federal Emergency Management Agency Hazard Identification Branch Mitigation Directorate 500 C Street, SW Washington, DC 20472	Intended for use in areas studied by approximate methods (Zone A) only. May be used to develop water-surface elevations at one cross section or a series of cross sections. May not be used to develop a floodway. Public Domain: Yes
One-Dimensional Steady Flow Models	HY8 4.1 and up (Nov. 1992)	U.S. Department of Transportation, Federal Highway Administration (FHWA)	Federal Highway Administration (FHWA) Hydraulics Engineering—Software Descriptions	Computes water-surface elevations for flow through multiple parallel culverts and over the road embankment. Software and related publication are available from Center for Microcomputers in Transportation (McTrans), University of Florida, 512 Weil Hall, Gainesville, FL 32611-6585 Public Domain: Yes

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis (*Continued*)				
	WSPGW 12.96 (Oct. 2000)	Los Angeles Flood Control District and Joseph E. Bonadiman & Associates, Inc.	Joseph E. Bonadiman & Associates, Inc. 588 West 6th Street San Bernardino, CA 92410	Windows version of WSPG. Computes water-surface profiles and pressure gradients for open channels and closed conduits. Can analyze multiple parallel pipes. Road overtopping cannot be computed. Open channels are analyzed using the standard step method, but roughness coefficient cannot vary across the channel. Overbank analyses cannot be done. Multiple parallel pipe analysis assumes equal distribution between pipes, so pipes must be of similar material, geometry, slope, and inlet configuration. Floodway function is not available. Demo version available from CivilDesign Public Domain: No
	Storm CAD v.4 (Jun. 2002) and v.5 (Jan. 2003)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499	Perform backwater calculations. Should not be used for systems with more than two steep pipes (e.g., supercritical conditions). Inflow is computed by using the Rational Method; the program is applicable only to watershed that has the drainage area to each inlet less than 300 acres. Public Domain: No
	PondPack v.8 (May 2002)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499	Cannot model ineffective flow areas. HEC-RAS or an equivalent program must be used to model tailwater conditions when ineffective flow areas must be considered. Public Domain: No
	Culvert Master v.2.0 (Sept. 2000)	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499	Compute headwater elevations for circular concrete and RCB culverts for various flow conditions. Public Domain: No

	XP-SWMM 8.52	XP Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	XP-SWMM cannot represent more than three Manning's *n* values per channel section. Where more than this number of values per section are required, the user must demonstrate the three *n* values for the entire section at various depths. Public Domain: No
	Xpstorm 10.0 May (2006)	XP Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	Xpstorm has the same stormwater modeling capability as the XP-SWMM program.
One-Dimensional Unsteady Flow Models	HEC-RAS 3.1.1	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable. Version 3.1 cannot create detailed output for multiple profiles in the report file. CHECK-RAS cannot extract data. Public Domain: Yes
	FEQ 9.98 and FEQUTL 5.46 (2005, both), FEQ 8.92 and FEQUTL 4.68 (1999, both)	Delbert D. Franz, Linsley, Kraeger Associates; and Charles S. Melching, USGS	U.S. Geological Survey 221 North Broadway Avenue Urbana, IL 61801 Online technical support	The FEQ model is a computer program for the solution of full, dynamic equations of motion for one-dimensional unsteady flow in open channels and control structures. The hydraulic characteristics for the floodplain (including the channel, over banks, and all control structures affecting the movement of flow) are computed by its companion program FEQUTL and need verification with results obtained using methodology or models accepted for NFIP use. Floodway concept formulation is unavailable. Public Domain: Yes
	ICPR 2.20 (Oct. 2000) and 3.02 (Nov. 2002)	Streamline Technologies, Inc.	Streamline Technologies, Inc. 6961 University Boulevard Winter Park, FL 32792	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation unavailable; however, version 3 allows user to specify encroachment stations to cut off the cross section. Public Domain: No

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis (*Continued*)				
	SWMM 4.30 (May 1994), and 4.31 (Jan. 1997)	U.S. Environmental Protection Agency and Oregon State University	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720 Department of Civil, Construction, and Environmental Engineering Oregon State University 202 Apperson Hall Corvallis, OR 97331-2302	Calibration or verification to the actual flood events highly recommended. Structural loss calculations unavailable and must be accommodated via roughness factor manipulation. Floodway concept formulation unavailable. Preferably, for NFIP purposes, head losses at bridges should be verified using WSPRO; losses at culverts should be verified using the U.S. Geological Survey's six equations for culvert analysis. Losses at storm sewer junctions should also be verified with separate calculations; contact FEMA for guidance with these calculations. View supporting documentation for floodway calculations. Public Domain: Yes
One-Dimensional Unsteady Flow Models	SWMM 5 Version 5.0.005	U.S. Environmental Protection Agency	Water Supply and Water Resources Division U.S. Environmental Protection Agency	SWMM 5 provides an integrated environment for editing study area input data, running hydrologic simulations, and viewing the results in a variety of formats. Public Domain: Yes
	FLDWAV (Nov. 1998)	National Weather Service	Hydrologic Research Laboratory Office of Hydrology National Weather Service NOAA 1345 East-West Highway Silver Spring, MD 20910	Includes all the features of DAMBRK and DWOPER plus additional capabilities. It is a computer program for the solution of the fully dynamic equations of motion for one-dimensional flow in open channels and control structures. Floodway concept formulation is unavailable. Calibration to actual flood events required. This model has the capability to model sediment transport. Program is supported by NWS. View supporting documentation. Public Domain: Yes
	MIKE 11 HD (2002 D, 2004, 2005, 2007)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Hydrodynamic model for the solution for the fully dynamic equations of motion for one-dimensional flow in open channels and control structures. The floodplain can be modeled separately from the main channel. Calibration to actual flood events is highly recommended. Floodway concept formulation is

				available for steady flow conditions. This model has the capability to model sediment transport. Public Domain: No
	FLO-2D v.2003.6, 2004.10 and 2006.1	Jimmy S. O'Brien	FLO-2D Software, Inc. P.O. Box 66 Nutrioso, AZ 85932	Hydrodynamic model for the solution of the fully dynamic equations of motion for one-dimensional flow in one channel and two-dimensional flow in the floodplain. Bridge or culvert computations must be accomplished external to FLO-2D using methodologies or models accepted for NFIP usage. Calibration to actual flood events required. Floodway computation is unavailable. Public Domain: Yes
	XP-SWMM 8.52 and up	XP Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	XP-SWMM cannot represent more than three Manning's *n* values per channel per channel section. Where more than this number of values per section are *n* value for the entire section at various depths. Calibration to actual flood events required. The floodway procedures are for unsteady flow floodway calculation. Public Domain: No
	XPstorm 10.0 (May 2006)	XP Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	Xpstorm has the same stormwater modeling capability as the XP-SWMM program.
Two-Dimensional Steady/Unsteady Flow Models	TABS RMA2 v. 4.3 (Oct. 1996)	U.S. Army Corps of Engineers	Coastal Engineering Research Center Department of the Army Waterways Experiment Station Corps of Engineers 3909 Halls Ferry Road Vicksburg, MS 39180-6199	Limitations on split flows. Floodway concept formulation unavailable. More review anticipated for treatment of structures. Public Domain: Yes
	FESWMS 2DH 1.1 and up (Jun. 1995)	U.S. Geological Survey	U.S. Geological Survey National Center 12201 Sunrise Valley Drive Reston, VA 22092	Region 10 has conducted study in Oregon. Floodway concept formulation unavailable. This model has the capability to model sediment transport. Public Domain: Yes

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis (*Continued*)				
	FLO-2D v. 2003.6, 2004.10, and 2006.1	Jimmy S. O'Brien	FLO-2D Software, Inc. Tetra Tech, ISG P.O. Box 66 Nutrioso, AZ 85932 www.flo-2d.com	Hydrodynamic model that has the capabilities of modeling unconfined flows, complex channels, used for alluvial fan modeling. Floodway option is under review.
	MIKE Flood HD 2002 D, 2004, 2005, and 2007	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	A dynamic coupling of MIKE 11 (one-dimensional) and MIKE 21 (two-dimensional) model. Solves the fully dynamic equations of motion for one- and two-dimensional flow in open channels, riverine floodplains, alluvial fans, and in coastal zones. This allows for embedding of subgrid features as 1-D links within a 2-D modeling domain. Examples of subgrid features could include small channels, culverts, weirs, gates, bridges, and other control structures. Calibration for actual flood events is highly recommended. Public Domain: No
Hydrologic Models: Determination of Flood Hydrographs				
Single Event	HEC-1 4.0.1 and up (May 1991)	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters. Public Domain: Yes
	HEC-HMS 1.1 and up (Mar. 1998)	U.S. Army Corps of Engineers	U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) 609 Second Street Davis, CA 95616-4687	The Hydrologic Modeling System provides a variety of options for simulation precipitation-runoff processes. It has the capability to use gridded rainfall data to simulate runoff. It does not provide snowmelt and snowfall functions; it cannot be used for areas where snowmelt is an important flood hazard source and must be considered in estimation of flood discharges. Public Domain: Yes

	TR-20 (Feb. 1992)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	Flood hydrographs at different locations along streams. Calibration runs preferred to determine model parameters. Public Domain: Yes
	TR-20 Win 1.00.002 (Jan. 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	The TR-20 computer model has been revised and completely rewritten as a Windows-based program. It is a storm event surface water hydrologic model applied at a watershed scale that can generate, route, and combine hydrographs at points within a watershed. Public Domain: Yes
	TR-55 (June 1986)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	Peak discharges and flood hydrographs at a single location. Public Domain: Yes
	WinTR-55 1.0.08 (Jan. 2005)	U.S. Department of Agriculture, Natural Resources Conservation Service	U.S. Department of Agriculture, Natural Resources Conservation Service	The new WinTR-55 uses the WinTR-20 program as the driving engine for analysis of the hydrology of the small watershed system being studied. Public Domain: Yes
Single Event	SWMM (RUNOFF) 4.30 (May 1994), and 4.31 (Jan. 1997)	U.S. Environmental Protection Agency and Oregon State University	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720 Department of Civil, Construction, and Environmental Engineering Oregon State University 202 Apperson Hall Corvallis, OR 97331-2302	Calibration or verification to the actual flood events highly recommended. Public Domain: Yes

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Hydrologic Models: Determination of Flood Hydrographs (*Continued*)				
	SWMM 5 Version 5.0.005 (May 2005) and up	U.S. Environmental Protection Agency	Water Supply and Water Resources Division U.S. Environmental Protection Agency	SWMM 5 provides an integrated environment for editing study area input data, running hydrologic simulations, and viewing the results in a variety of formats. These include color-coded drainage area and conveyance system maps, time series graphs and tables, profile plots, and statistical frequency analyses. Public Domain: Yes
	MIKE 11 UHM (2002 D, 2004)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	Simulates flood hydrographs at different locations along streams using unit hydrograph techniques. Three methods are available for calculating infiltration losses and three methods for converting rainfall excess to runoff, including SCS Unit hydrograph method. View the Rainfall-Runoff Module Description. Public Domain: No
	PondPack v.8 (May 2002) and up	Haestad Methods, Inc.	Haestad Methods, Inc. 37 Brookside Road Waterbury, CT 06708-1499	The program is for analyzing watershed networks and aiding in sizing detention or retention ponds. Only the NRCS Unit Hydrograph method and NRCS Tc calculation formulas are acceptable. Other hydrograph generation methods or Tc formulas approved by state agencies in charge of flood control or floodplain management are acceptable for use within the subject state. Public Domain: No
Single Event	XP-SWMM 8.52 and up	XP-Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	Model must be calibrated to observed flows, or discharge per unit area must be shown to be reasonable in comparison to nearby gauge data, regression equations, or other accepted standards for 1 percent annual chance events. Public Domain: No
	Xpstorm 10.0 (May 2006)	XP Software	XP Software 700 NE Multnomah St. Suite 230 Portland, OR 97232	Xpstorm has the same stormwater modeling capability as the XP-SWMM program.

Continuous Event	HSPF 10.10 and up (Dec. 1993)	U.S. Environmental Protection Agency, U.S. Geological Survey	Center for Exposure Assessment Modeling U.S. Environmental Protection Agency Office of Research and Development Environmental Research Laboratory 960 College Station Road Athens, GA 30605-2720	Calibration to actual flood events required. Water Resources Application Software. Public Domain: Yes
	MIKE 11 RR (2002 D, 2004)	DHI Water and Environment	DHI, Inc. 319 SW Washington St. Suite 614 Portland, OR 97204	The Rainfall-Runoff Module (RR, formerly NAM) is a lumped-parameter hydrologic model capable of continuously accounting for water storage in surface and subsurface zones. Flood hydrographs are estimated at different locations along streams. Calibration to actual flood events is required. View the MIKE 11 Add-On Modules. Public Domain: No
	PRMS Version 2.1 (Jan. 1996)	U.S. Geological Survey	U.S. Geological Survey 12201 Sunshine Valley Drive Reston, VA 22092 U.S. Geological Survey P.O. Box 25046, Mail Stop 412 Denver Federal Center Lakewood, CO 80225-0046	PRMS is a modular-designed, deterministic, distributed-parameter modeling system that can be used to estimate flood peaks and volumes for floodplain mapping studies. Calibration to actual flood events required. The program can be implemented within the Modular Modeling System (MMS) that facilitates the user interface with PRMS, input and output of data, graphical display of the data, and an interface with GIS. Public Domain: Yes
Statistical Models				
Statistical Models	HEC FFA 3.1 (February 1995)	U.S. Army Corps of Engineers	Water Resources Support Center Corps of Engineers Hydrologic Engineering Center 609 Second Street Davis, CA 95616-4687	Performs flood frequency analyses following *Bulletin 17B, Guidelines for Determining Flood Flow Frequency,* prepared by the Interagency Advisory Committee on Water Data (1982). Supersedes HECWRC. Public Domain: Yes
	PEAKFQ 2.4 and up (April 1998)	U.S. Geological Survey	U.S. Geological Survey Hydrologic Analysis Software Support Team 437 National Center Reston, VA 20192	Performs flood frequency analyses following *Bulletin 17B, Guidelines for Determining Flood Flow Frequency,* prepared by the Interagency Advisory Committee on Water Data (1982). Public Domain: Yes

NUMERICAL MODELS ACCEPTED BY FEMA FOR NFIP USAGE (*Continued*)

Type	Program	Developed by	Available from	Comments
Statistical Models (*Continued*)				
	FAN	FEMA	Michael Baker, Jr., Inc. 3601 Eisenhower Avenue, Suite 130 Alexandria, VA 22304	Determines depth and velocity zones over alluvial fans. Public Domain: Yes
Locally Accepted Hydraulic Models: Determination of Water-Surface Elevations for Riverine Analysis				
One-Dimensional Unsteady Flow Models	HCSWMM 4.31B (Aug. 2000)	Stormwater Management Section, Public Works Department, Hillsborough County, Florida	Stormwater Management Section Public Works Department Hillsborough County, Florida 601 E. Kennedy Boulevard, 21st Floor P.O. Box 1110 Tampa, FL 33601	Modified version of EPA SWMM 4.31. The major modifications are: integrated the SCS-CN method into the model to calculate the rainfall-runoff process; allows up to 21 different Manning's coefficients for each cross-section; added 4 more fields to C1 line to calculate the exit, entrance, and other minor losses, and to stretch the pipe based on stability condition; automatically creates an ASCII file, HYDROG.DAT, containing hydrograph for each subbasin generated after each run. **Only accepted for usage and applicable within** Hillsborough County, Florida. Public Domain: Yes
	NETWORK Jun. 2002)	Southwest Florida Water Management District	Engineering Section Resource Management Department 2329 Broad Street Brooksville, FL 34604-6899	Interconnected ponds and channels routing model. **Only accepted for usage within Southwest Florida Water Management District.** Public Domain: Yes
	CHAN for Windows v.2.03 (1997)	Aquarian Software, Inc.	Aquarian Software 1415 Briercliff Drive Orlando, FL 34604-6899	Calibration or verification to the actual flood events highly recommended. Floodway concept formulation is unavailable. Encroachment stations can be specified in editor to cut off section. **Only accepted for usage within Southwest Florida Water Management District.** Public Domain: No
Two-Dimensional Unsteady Flow Models	S2DMM (Feb. 2005)	Tomasello Consulting Engineers, Inc.	Tomasello Consulting Engineers, Inc. 5906 Center Street Jupiter, FL 33458	Applicable to a network of rectangular grids. Capable of routings on natural overland sheetflow areas and water management systems with cascading lakes and channels. Computing runoff from either daily or hourly rainfall with design distributions,

				using SCS formula with soil storage and soil moisture updated on daily basis. Stage/storage, sheetflow cross sections, and soil types are represented in each computational grid entered via GIS. HEC-2 type cross sections can be entered on specific channel grids, and minor channels can be embedded on general grids. Evapotranspiration computations are based on seasonal factors and soil moisture of unsaturated and saturated zones. Interactions with the subsurface conditions are handled by MODFLOW routines. Capable of simulating continuous hydrologic conditions. Cannot compute regulatory floodway. **Only accepted for usage in the South Florida Water Management District.** Public Domain: No
Two-Dimensional Steady/Unsteady Flow Models	DHM 21 and 34 (Aug. 1987)	Theodore V. Hromadka II and Chung-Cheng Yen	Hromadka & Associate Costa Mesa, CA	Diffusion flow model which can route unconfined surface and open channel flows. Can be used to model alluvial flooding. Rainfall-runoff output can be used for hydrologic studies. Kinematic routing optional. Floodway concept formulation unavailable. Calibration to actual flood events is recommended. **Only accepted for usage within the San Bernardino County Flood Control District, California.** Public Domain: No
Locally Accepted Hydrologic Models: Determination of Flood Hydrographs				
Single Event	AHYMO 97 (Aug. 1997)	Albuquerque Metropolitan Arroyo Flood Control Authority, Anderson-Hydro	Anderson-Hydro 13537 Terragon Drive, NE Albuquerque, NM 87112	Flood hydrographs at different locations along streams. **Only accepted for usage and the default parameters in the model applicable within New Mexico.** Information on the AHYMO model. Public Domain: Yes
	Colorado Urban Hydrograph Procedure (CUHPF/PC) (May 1996 and May 2002)	Denver Urban Drainage and Flood Control District	Denver Urban Drainage and Flood Control District 2480 West 26th Avenue Suite 156-B Denver, CO 80211	Flood hydrographs at different locations along streams. Hydrographs are routed using UDSWM2-PC (a modified version of the Runoff Block of EPA's SWMM). **Only accepted for usage and the default parameters in the model applicable within the Denver, Colorado, metro area.** Public Domain: Yes

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ENGINEERS & SURVEYORS INSTITUTE
Peer Review Checklist
FAIRFAX COUNTY

SUBDIVISION PLAN
First Submission [*] = Plan non acceptable if any * box is marked w/o explanation on plan or alternate solution noted

Plan Name ______________________ Plan #______________________ District ______________
Submitting Firm ______________________ Project Coordinator ______________________
Designated Plan Examiner #______ Name ______________________ Phone #______________
Review Date __________ ESI Reviewer ______________________ Reviewer's Firm ______________________

CODE SECTION	REQUIREMENT	SHEET Optional	OK	NO	N/A	LINE
LTI 07-05	Cover sheet 1-10-07 edition used			*		1
112-2-302, 3&4	Concurrent processing approval documented					2
LTI 07-05	Fire Marshall note and data filled in (fire flow, source of fire flow)					3
LTI 07-05	SWM facility data filled in					4
LTI 07-02	Shape factor for each lot filled in					5
PFM 10-0301.1	Solid waste statement filled in and is accurate (peer review confirm)					6
OSDS ltr # 03-12	Site tabulations filled in			*		7
OSDS ltr # 03-12	Zoning requirements completed, verify zoning and if proffered by an * after rezoning number on zoning map book			*		8
LTI 07-05	Plan approval information completed (identification numbers and sheet numbers, etc.) per new updated cover sheet version of 1-10-07.					9
107-1-2(a)	Does plan approval information note that a soil report is required if construction is proposed in an "A" soil or a dam is proposed requiring a report per PFM Plate # 64-6?					10
OSDS ltr # 03-12	Review fee computation filled in					11
OSDS ltr # 03-12	Vicinity map adequate and to 1"=2000' scale or greater					12
PFM 8 Table 8.4	Vicinity map shows sidewalk and trail maintenance responsibility (letter 16-87)					13
OSDS ltr # 03-12	Soil map shown			*		14
OSDS ltr # 03-12	Soil data chart filled in			*		15
OSDS ltr # 03-12	Lot tabulated by soil type			*		16
OSDS ltr # 03-12	Tax map reference number(s) filled in and correct (peer review confirm)					17
OSDS ltr # 03-12	Sanitary treatment plant filled in					18
OSDS ltr # 03-12	Watershed identified					19
OSDS ltr # 03-12	Disturbed area within watershed filled in					20
112-2-806	Number of affordable dwelling units provided on this plan (if entire project contains 50 units or more)			*		21
101-2-4(a)	Engineer's or surveyor's certification completed with seal and date (original signature and seal on at least 1 cover sheet) ESI Tech Bulletin vol.5 #3			*		22
OSDS ltr # 03-12	Geotech engineer's/other professional seal/signature/date (original signature and date on at least 1 cover sheet)					23
PFM 2-0212.19	Owner/developer wetlands certification signed			*		24
OSDS ltr # 03-12	District shown and is correct			*		25
	PLANNING AND ZONING					26
112-2-308	Density, lot area, width conform to requirements (112-2-306)					27
OSDS ltr # 03-12	Rezoning number with date and page number is on plan approval information					28
DEM ltr # 9-90	Plan includes clerk of BOS rezoning approval letter to applicant			*		29

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CODE SECTION	REQUIREMENT	SHEET Optional	OK	NO	N/A	LINE
	including any waivers approved by BOS					
DEM ltr # 9-90	Plan includes BOS rezoning resolution			*		30
PFM 2-0101.1	Proffers included on plan if applicable			*		31
PFM 2-0101.1	GDP/FDP included on plan if applicable			*		32
PFM 2-0101.1	Cluster or variances/Special Exception/Special Permit included			*		33
DEM ltr # 9-90	Clerk to BOS/BZA approval letter to applicant included			*		34
DEM ltr # 9-90	Special Permit/Special Exception plat included in plan with approved conditions			*		35
DEM ltr # 9-90	Valid Special Permit/Special Exception (not expired)			*		36
	Proffer/Development condition narrative included			*		37
112-18-204.4	Compliance with proffers, Special Permit/Special Exception conditions			*		38
112-18-204.4	Compliance with GDP, FDP, Special Permit/Special Exception plan layout			*		39
101-2-3(d)(4)	Valid preliminary plat, if subdividing without GDP			*		40
112-2-806	Location of affordable housing units, noted if entire project contains 50 dwelling units or more			*		41
	Required grave burial ground statement, or "none"					42
	PUBLIC STREET REQUIREMENTS					43
101-2-2(2)	Street names shown for existing and proposed streets					44
PFM 7-0404.21.B	Route number shown for existing state maintained streets					45
PFM 7-0404.1	Centerlines shown for existing and proposed streets					46
PFM 7-0404.1	Centerline stationing shown in plan view for existing and proposed streets					47
101-2-3(c)(4)	Street widths, pavement and right-of-way shown for existing and proposed streets plus distance from property line to centerline					48
PFM 7-0104.1	Construction of dedicated service drive on primary highways			*		49
PFM 7-0201.1.C.	Existing right of way dedicated if VDOT frontage not present (Deed Book and page number shown)					50
PFM 7-0405.2	Intersection and entrance sight distance (horizontal and profile) for all existing and proposed entrances			*		51
PFM 7-0404.6	Profiles shown for all new streets including widening and turn lanes for existing roads			*		52
PFM 7-0105.1	At existing street intersections, posted speed shown for existing road			*		53
PFM 7-0105.1	Street category and traffic volume shown for each new street			*		54
PFM 7-0105.1	Curve data shown to conform with street category for new streets					55
PFM 7-0107.5.A.	Stop or yield signs at all intersections					56
PFM 7-0401.1A&B	Handicapped ramps at all curb returns					57
	PRIVATE STREETS					58
112-11-304	Ingress/egress easement noted or delineated for all private streets					59
PFM Std TU-1	Typical cross section and turnaround for private streets					60
112-11-302.2	Private residential streets not exceed 600'(182.88 m) without waiver					61
PFM 2-103.6	Private street maintenance note on plan and plat (agency)					62
PFM 23-7 PS-3	Pipestem driveway pavement design shown					63
	DRAINAGE					64
PFM 6-0202.13	Overland relief provided for sump conditions and to clear building					65
PFM 6-1103.3	Inlet ponding to be within an easement					66
PFM 6-1405.1	Flood plain easement provided and reference to flood plain study number					67
PFM 2-0203.1.C	Limit of clearing and grading shown					68
OSDS ltr. 03-01	Priority Rating Form for E&S Control					69
OSDS ltr. 03-11	Completed, Certified E&S Control Checklist					70
PFM 11-0104.1	2 phase plans provided for erosion and sedimentation control					71

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CODE SECTION	REQUIREMENT	SHEET Optional	OK	NO	N/A	LINE
PFM 11-0104.1	1st stage phase 1 limits of clearing only to install perimeter controls					72
DEM ltr #30-88	Erosion and sedimentation controls identified and trap computations shown					73
DEM ltr #30-88	Calculations provided to insure adequacy of sediment basins					74
PFM 2-0212.12	Clearing limits matches between : grading, erosion and sediment, GDP sheets					75
PFM 6-0202.5	No concentrated surface water discharged offsite without easements					76
PFM 6-0905,1008	Design computations provided for closed and open systems					77
PFM 6-0203.1.B	Outfall narrative description with adequacy conclusion			*		78
PFM 6-0201.2	If open channel , is it an existing natural incised channel					79
PFM 6-0203.1.A.	Cross section, water surface elevation and computations shown for existing natural incised channel			*		80
PFM 6-0203.1.A.	If incised channel, show both horizontal and vertical scale			*		81
PFM 6-0203.3.	If into existing system, include its capacity computations and proposed flow			*		82
PFM 6-0301.3	SWM facility provided on-site with required calculations			*		83
PFM 6-0301.3	SWM provided off-site, plan number and approval date shown			*		84
DEM ltr 7-87	Waiver to be requested to use offsite stormwater management			*		85
OSDS ltr # 03-12	Waiver request on plan approval information and ID number shown					86
PFM 6-0401.2	BMP facility provided on-site with required calculations			*		87
PFM 6-0402.8(f)	Computations of BMP phosphorus removal			*		88
PFM 6-0402.3	BMP provided off-site plan number and approval date shown			*		89
PFM 6-0401.3	BMP water quality waiver requested if facility not shown or referenced			*		90
OSDS ltr # 03-12	BMP waiver request on plan approval information with ID number			*		91
PFM 6-0402.8(A)	BMP narrative summary included how water quality is provided					92
PFM 6-1701.3	Resource Protection Area boundary shown if it is within the site			*		93
PFM 6-0303.3.	SWM and BMP not in RPA without approved exception					94
PFM 6-0402.8(g)	BMP maintenance responsibility statement (agency)					95
PFM 6-0402.8(c)	BMP open space credit note "water quality management area…"					96
	DAM STANDARDS INFORMATION					97
PFM 6-1604.2	Emergency spillway placed in undisturbed ground and shown with dam profile					98
PFM 6-1604.6	Justification provided if a combined spillway is proposed					99
PFM 6-1602.6	Easement provided to carry maximum emergency spillway flow and extends to adequate drainage system					100
PFM 6-1603.4	Dam breach analysis performed for drainage area = > 28ha. (69Ac.)					101
PFM 6-1605.5A.2	Spillway outfall conduit RCP 18" (450 mm) or greater					102
PFM 6-1605.3A	Dam clearing limits extend at least 10' (3 m) beyond toe					103
PFM 6-1605.1b	Dam category determined per plate 64-6					104
PFM 6-1607.1B(2)	Concrete cradle on upper 2/3 length of conduit (plate 64-6)					105
PFM 6-1605.5B(1)	Filter blanket around lower 1/3 of conduit					106
PFM 6-1605.6a2	Top width of dam minimum of 12' (3.7 m)					107
PFM 6-1607-1B (4)(a)	Plan specifies principal spillway pipe to meet AWWA spec. C300 or C301, wet pond.					108
PFM 6-1607.1B (4)(b)	Plan specifies principal spillway pipe to meet ASTM spec C361, Dry Pond.					109
PFM 6-1606.2G	20' (6.1 m) cleared access easement required along down stream dam toe					110
PFM 6-1606.2G	Access road has a separate standard entrance at the street with a gate					111
PFM 6-1604.10	Low-level water release required within principal spillway/wet ponds					112
PFM6-1606.1C&D	Benches provided for dams 15' (4.5m) high or greater & in wet ponds					113

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CODE SECTION	REQUIREMENT	SHEET Optional	OK	NO	N/A	LINE
PFM 6-1305.4	No trees or landscaping on earth dams					114
PFM 6-1305.5	Dam restrictive planting easement and notes provided					115
PFM 6-1306.3D	Separate maintenance access easement provided for ponds to be publicly maintained if crossing another parcel					116
PFM 6-1306.3F	12' (3.7 m) wide all weather surface for access road to SWM facility per Plates 49-6, 50-6, 56-6 or 57-6					117
PFM 6-1306.3J	Removable trash rack detail provided, if underground, access shall be immediately above rack					118
PFM6-1604.8B&C	Trash rack provided for low flow orifice					119
	LANDSCAPING & TREE COVER					120
PFM 12-0403.2.B.	Drip line shown for trees to be retained					121
PFM 12-0403.8.C.	Tree cover computations shown with landscape plan and plant schedule			*		122
PFM 12-0403.10.	Tree protection shown and identified					123
	MISCELLANEOUS					124
PFM 2-0201.6	Plan is drawn to a scale of not less than 1:500					125
PFM 2-0212.3	North arrow and reference to State Grid System (VCS 83)					126
ESI Tech Bul 5-3	All sheets have engineer's or surveyor's seal and signature			*		127
ESI Tech Bul 5-3	At least one set of plans has original signature and date on seal on cover sheet from each professional. APELSLA Board R&R 12.8.B.			*		128
	Match lines shown where sheets join					129
PFM 2-0107.1A	Existing topography drawn at 2' (0.5 m) intervals					130
PFM 2-0107.1	Proposed grading shown by contours and spot elevations					131
101-2-3(c)(3)	Owner or lot number, zone and current use of all adjoining property					132
PFM 10-0104.2.C	Bearings and distances on centerlines of sanitary sewers					133
PFM-10-0104.2.A.	Sanitary sewer profiles on same sheet as plan					134
PFM 10-0102.5.C.	Sanitary sewer setback 15' (4.6 m) from all buildings					135
101-2-3(c)(4)	Existing easements of record shown with deed book and page number					136
101-2-3(c)(4)	Proposed easements shown and identified as "proposed" otherwise Deed Book and page number shown					137
PFM 8-0100	Sidewalk provided along the site's road frontage if required					138
PFM 8-0201.3	Trails provided in accordance with the Comprehensive Trails Plan					139
112-16-403	Trails and walks as shown on GDP, FDP, SE, SP					140
PFM 8-0202.4A	Profiles shown for all trails to be constructed					141
PFM 2-0209.1.F	Recreation equipment located and listed where proffered or required in "P" district or development plan					142
PFM 2-0101.1	Approved or requested waiver and/or modification letters on plan					143
PFM 2-0101.1	All waivers and variances are still valid and not expired					144
PFM 2-0101.1	All conditions of waivers complied with on plan					145
PFM 2-0404.2	Vertical and horizontal location of certain existing transmission lines shown					146
PRINTS	Prints legible, not too light or too dark to microfilm					147
MUST	Existing topography not screened excessively so as not legible					148
MICROFILM	Insufficient elevation numbers on existing contour lines					149
	FIRE AND RESCUE DEPARTMENT ISSUES					150
PFM 9-0202.2.J1	Emergency access to within 100' (30 m) of main entrance					151
Fire Marshal	Fire lanes location marked on separate plan sheet					152
PFM 9-0202.2J(5)	Fire lanes a minimum of 18' (5.5 m) wide					153
	FAIRFAX COUNTY WATER AUTHORITY ISSUES					154
PFM 9-0102.6A	Proposed tie-ins to existing water system shown			*		155
PFM 9-0102.3A	Sizes of proposed water mains and locations indicated			*		156
PFM 9-0102.7A	Existing easements with Deed Book and Page Number provided					157
PFM 9-0102.6C	Profile all proposed public water mains included			*		158

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Peer Review Subdivision Plan Page 5 of 6

CODE SECTION	REQUIREMENT	SHEET Optional	OK	NO	N/A	LINE
per FCWA request	Provide water main stationing on the profile			*		159
PFM 9-0102.3D & .6D	Show utility crossings on the profiles			*		160
PFM 9-0102.6H	Test holes results for all crossings with less than 1' (0.3 m) vertical clearance					161

PEER REVIEWER : COMPLETE NEXT PAGE -- FOR PLAN CONTROL EARLY ROUTING INFORMATION.

Note to Peer Reviewer: The Peer Review Team has been requested to assist Plan Control in identifying the necessary distribution of plans to agencies that are not involved in the normal review function. This will allow the plan to be distributed to those agencies in a more timely fashion.

Site/Subdivision Plan Routing Slip

FROM: ESI PEER REVIEW

TO: PLAN CONTROL

Plan Name: __________________ Plan Number: _____________________ Date:_____________

This plan should be routed to the Agencies indicated
(Peer Reviewer; Circle Reasons for additional reviews needed and reference proffer #)

AGENCY	YES	PROFFER/CONDITION #	N/A
Urban Forestry Any plan which has a rezoning, special exception, special user permit or variance			
Park Authority (Proffer to get Park Authority review/Work on Park Land/Dedication To Park/ Site is Adjacent To Park/BOS Directed Park Review			
Heritage Resources (Proffer/Condition/Directed Review by BOS or Historic Overlay District)			
Planning Commission (BOS Directed PC Review)			
Board of Supervisors (BOS Directed BOS review)			
Health Department (Septic/Well/Pool)			
NVSWCD (Co Project/Pohick Watershed/within 3 miles of Potomac river)			
Other			

When peer review has been completed and both the plan and the checklist have been reviewed by ESI staff reviewer, remove this sheet from the checklist and wrap it around the plan and put the plan in the pigeon hole for “ESI peer review plans OK to log in”.

LEED for New Construction v2.2
Registered Project Checklist

Project Name:
Project Address:

Yes	?	No			
				Sustainable Sites	**14 Points**
Y			Prereq 1	**Construction Activity Pollution Prevention**	Required
			Credit 1	**Site Selection**	1
			Credit 2	**Development Density & Community Connectivity**	1
			Credit 3	**Brownfield Redevelopment**	1
			Credit 4.1	**Alternative Transportation**, Public Transportation Access	1
			Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms	1
			Credit 4.3	**Alternative Transportation**, Low-Emitting & Fuel-Efficient Vehicles	1
			Credit 4.4	**Alternative Transportation**, Parking Capacity	1
			Credit 5.1	**Site Development,** Protect of Restore Habitat	1
			Credit 5.2	**Site Development,** Maximize Open Space	1
			Credit 6.1	**Stormwater Design,** Quantity Control	1
			Credit 6.2	**Stormwater Design,** Quality Control	1
			Credit 7.1	**Heat Island Effect,** Non-Roof	1
			Credit 7.2	**Heat Island Effect,** Roof	1
			Credit 8	**Light Pollution Reduction**	1

Yes	?	No			
				Water Efficiency	**5 Points**
			Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%	1
			Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation	1
			Credit 2	**Innovative Wastewater Technologies**	1
			Credit 3.1	**Water Use Reduction**, 20% Reduction	1
			Credit 3.2	**Water Use Reduction**, 30% Reduction	1

Yes	?	No			
				Energy & Atmosphere	**17 Points**
Y			Prereq 1	**Fundamental Commissioning of the Building Energy Systems**	Required
Y			Prereq 2	**Minimum Energy Performance**	Required
Y			Prereq 3	**Fundamental Refrigerant Management**	Required
			Credit 1	**Optimize Energy Performance**	1 to 10
				10.5% New Buildings or 3.5% Existing Building Renovations	1
				14% New Buildings or 7% Existing Building Renovations	2
				17.5% New Buildings or 10.5% Existing Building Renovations	3
				21% New Buildings or 14% Existing Building Renovations	4
				24.5% New Buildings or 17.5% Existing Building Renovations	5
				28% New Buildings or 21% Existing Building Renovations	6
				31.5% New Buildings or 24.5% Existing Building Renovations	7
				35% New Buildings or 28% Existing Building Renovations	8
				38.5% New Buildings or 31.5% Existing Building Renovations	9
				42% New Buildings or 35% Existing Building Renovations	10
			Credit 2	**On-Site Renewable Energy**	1 to 3
				2.5% Renewable Energy	1
				7.5% Renewable Energy	2
				12.5% Renewable Energy	3
			Credit 3	**Enhanced Commissioning**	1
			Credit 4	**Enhanced Refrigerant Management**	1
			Credit 5	**Measurement & Verification**	1
			Credit 6	**Green Power**	1

continued...

Yes	?	No		Materials & Resources	13 Points
Y			Prereq 1	**Storage & Collection of Recyclables**	Required
			Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
			Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1
			Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
			Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
			Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
			Credit 3.1	**Materials Reuse**, 5%	1
			Credit 3.2	**Materials Reuse**,10%	1
			Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1
			Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1
			Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regio	1
			Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regio	1
			Credit 6	**Rapidly Renewable Materials**	1
			Credit 7	**Certified Wood**	1

Yes	?	No		Indoor Environmental Quality	15 Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Outdoor Air Delivery Monitoring**	1
			Credit 2	**Increased Ventilation**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Lighting	1
			Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
			Credit 7.1	**Thermal Comfort**, Design	1
			Credit 7.2	**Thermal Comfort**, Verification	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

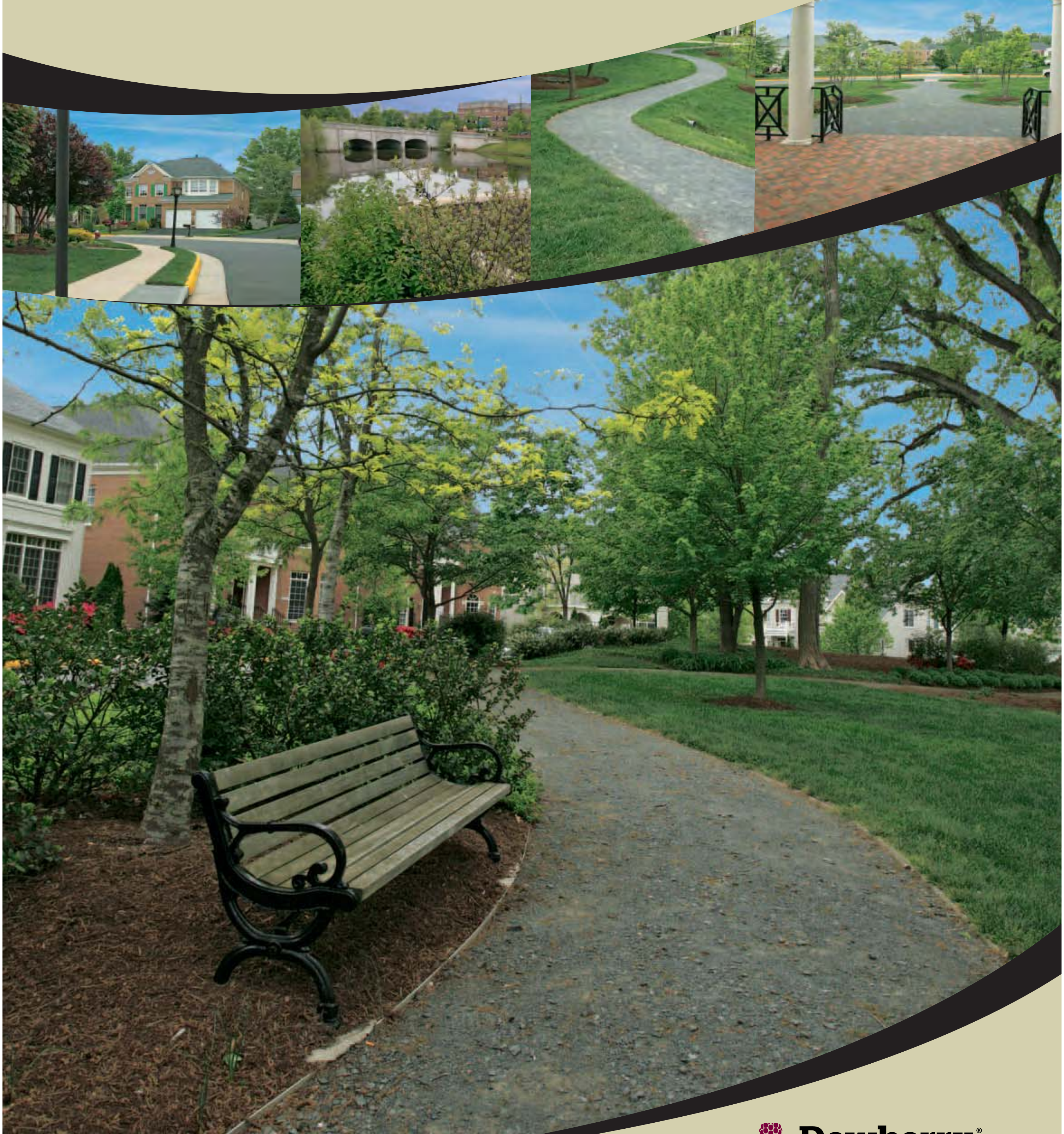
Yes	?	No		Innovation & Design Process	5 Points
			Credit 1.1	**Innovation in Design**: Provide Specific Title	1
			Credit 1.2	**Innovation in Design**: Provide Specific Title	1
			Credit 1.3	**Innovation in Design**: Provide Specific Title	1
			Credit 1.4	**Innovation in Design**: Provide Specific Title	1
			Credit 2	**LEED® Accredited Professional**	1

Yes	?	No		Project Totals (pre-certification estimates)	69 Points

Certified: 26-32 points, **Silver:** 33-38 points, **Gold:** 39-51 points, **Platinum:** 52-69 pc

Land Development Handbook

Third Edition Project Pages



Dewberry Project: Farrcoft, Virginia

Dewberry®

Farrcroft Community

Fairfax, Virginia

A: Main Street Entrance
B: Farrcroft Reserve
C: Daniel's Run Stream Valley
D: Old Lee Highway Entrance
E: Oak Park
F: Esplanade
G: Community Center

A 70-acre neighborhood of 270 homes adjacent to the historic Old Town District of Fairfax, Virginia, the Farrcroft community plan was developed over a two-year review process with the city and community groups. The plan, which represents a modified neo-traditional design, promotes a pedestrian scale to the community streets. In addition to refurbishment of the original Farr Manor House and grounds for community use, the restoration of Daniel's Run Stream Valley and preservation of the oak grove in Oak Park typify the sensitivity to the site's historic and natural features, which was integral to the public master plan process. Over the next five years, the developer's vision of a traditional, colonial community was permitted and constructed through a series of site plans further detailing the infrastructure improvements including the regional stormwater management wet pond with sediment forebay, extensive trail systems, frontage improvements along both Main Street and Old Lee Highway, entry monumentation enhancements including the three-span bridge, and traffic-calming features throughout. The first neighborhood of its kind in Fairfax, Farrcroft spurred further redevelopment efforts in the downtown core.

Brenman and Boothe Parks at Cameron Station

Alexandria, Virginia

Totaling 64 acres, Brenman and Boothe Parks bracket the ends of the former Cameron Station Military Complex in Alexandria. The complex was reconstructed as a major mixed-use, in-town community. The parks provide a high-profile recreational complex in the heart of the urban Alexandria community. Improvements include an extensive pathway network connecting proposed concessions/convenience facilities; pedestrian bridges; athletic fields; tennis, basketball, and volleyball courts; and an outdoor theater on the green. The park accommodates a regional bike path along the adjacent Backlick Run Stream.

The unique and complex challenge of this project was the transformation of a former 40-acre paved U.S. Army base with a stale stormwater management pond into a green urban park. Key aspects of the design include a tranquil pond with rolling slopes and pastoral views, meandering lakeside trails, and tournament-quality athletic facilities. The design team's creativity, coupled with the input of community-minded citizens, resulted in two parks widely regarded as the crowning achievement in the successful redevelopment of the former military complex into new and beneficial community uses.

Idlewild

Fredericksburg, Virginia

A: Entry from Route 3

B: Future School Site

C: Community Center

D: Village Center

E: Green

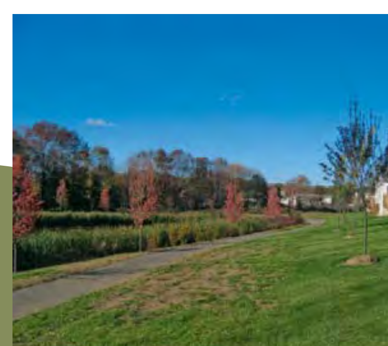
F: Stream Valley Parks

G: Entry from Route 1

Located within Fredericksburg, Virginia, the 432-acre Idlewild was master-planned, designed, and constructed with the city's rich heritage in mind. A major goal of the master plan was to promote a community organization, scale, and detail respectful of local tradition, history, and vernacular. The planned community of 785 residences is organized into three villages, each replete with pedestrian-scale streets and a series of parks. Major community open space, identified for dedication to the city, totals 151 acres; combined with 56 acres of community open space, this represents 48 percent of the total site. Major elements of the plan included a village green and adjacent convenience commercial and work-live residences, a broad community greenway leading from the lower stream valley to the historic Downman House ruins, an extensive stream valley trails network including dedication of the former rail line to the city's "rails to trails" program, a 27-acre school site, and a 14-acre public use site. The 785 residences include 585 single-family detached homes and 200 townhomes.

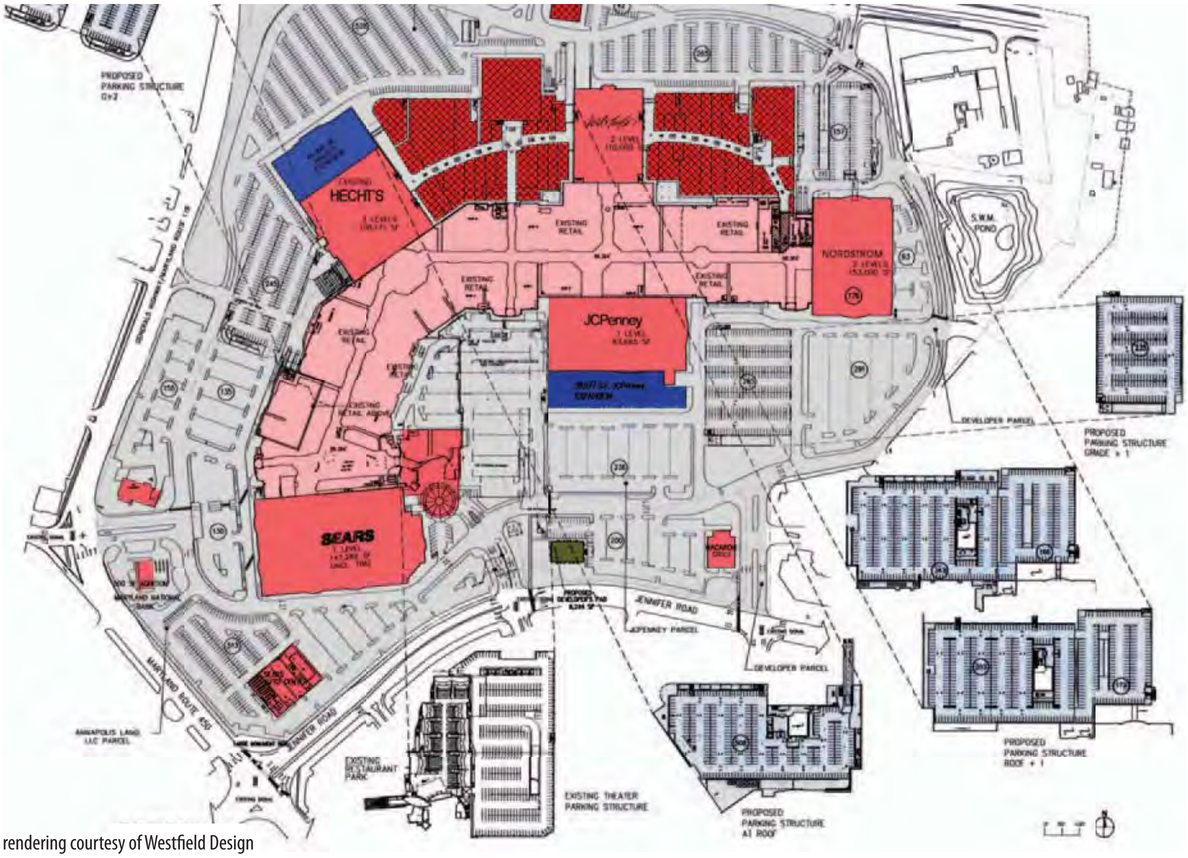
Greenbriar Horizon Active Adult Community
Burlington County, New Jersey

The Greenbriar Community consists of 240 active-adult single-family homes, a community center, related amenities, and improvements, including access roadways, lighting, landscaping, utilities, and stormwater management facilities. The design effort spanned preliminary review, due diligence assessment, concept refinement, preliminary grading analysis, preliminary and final major subdivision documents, regulatory agency permitting, environmental impact statement (EIS) preparation, traffic impact study, sanitary sewer system design, and New Jersey Department of Environmental Protection stream encroachment permitting. Initial site design on this project was completed on a fast-track schedule with only approximately one month from completing the survey to submitting it for township planning and zoning review. Design efforts focused on landscaping and buffering—especially along the New Jersey turnpike property line—in order to promote community privacy while still creating an active, accessible recreation area, streetscaping, and community identity through design of the entryways and emphasis on the community center—the true heart of the neighborhood.



Westfield Annapolis Mall

Annapolis, Maryland



rendering courtesy of Westfield Design

The redevelopment and expansion of Westfield Annapolis Mall included the addition of a 75,000-square-foot two-level anchor retail space and 224,182 square feet of additional retail space, totaling of 299,182 square feet of new gross floor area. Other improvements included in the redevelopment were two new, two-level parking structures, which tie into the second level of the existing anchor department stores, above the new retail.

In keeping with current trends in mall design, the exterior facade and open space was transformed to be more interactive at street level by improving the quality, safety, efficiency, and scale of the pedestrian-oriented streetscape. These changes were intended to improve mall and individual store access. Several pad sites were also built into the mall property to attract new accessory uses, not previously available at this location.

Swan Point

Charles County, Maryland

Swan Point is a resort development located in southern Charles County on the Potomac River. The project includes development of a hotel, redevelopment of an existing golf course and clubhouse, two marinas, and a residential component including luxury condo units, single-family detached and duplex units, and an active-adult component. The hotel and golf course provide a combination of services and amenities that are unique to this region, unmatched in their setting, design, and natural beauty.

This project presented a series of design challenges ranging from its environmentally sensitive location to its infrastructure requirements. The site includes both tidal and nontidal wetlands and several nesting areas for bald eagles and blue herons, both protected under federal regulations. Additionally, much of the site is within the Chesapeake Bay Critical Area and subject to enhanced stormwater management and buffer requirements. A low-impact development approach was used in the site design and stormwater management strategies, including vegetated swales and porous pavement.

The site required installation of a new 0.3 million-gallon-per-day capacity enhanced nutrient removal wastewater treatment plant that has future capacity. Upgrades to the existing potable water system were also required to serve the new development.

rendering courtesy of Canin Associates

Village Place

Gainesville, Virginia

Village Place is a mixed-use village center focusing on a traditional small-town main street design. The development plan provides a framework for incremental development of a variety of complementary buildings and spaces to create a rich venue in which to shop, live, and work. The concept relies on a traditional street grid with Main Street at its center, anchored on the south by a hotel and on the north by a ceremonial roundabout. The 65-acre center provides 475 dwelling units and 650,000 square feet of retail/employment and lodging uses.

Janelia Farm Research Campus

Loudoun County, Virginia

Located in rural Loudoun County, the Janelia Farm Research Campus embraced a low-impact development approach in its transformation of the 681-acre site. Maintaining over 600 acres as woods and meadows and developing only 60 acres, this project included extensive landscape architectural services for both the greenroof and site landscape; site, civil, and surveying services from utility design to plan permitting; and construction phase services—all critical to the success of a fast-track design-build project.

The campus includes a 450,000-square-foot research/laboratory building known as the Landscape Building due to its unique setting within the hillside sloping toward the Potomac River. The campus includes supporting housing consisting of a 100-room "hotel" connected to the Landscape Building via an underground pedestrian tunnel, and 56 individual long-term housing units. The renovation of a historic home overlooking the campus and the Potomac River is the site's main focal point.

The greenroof planting design incorporates an international meadow prairie theme along with hardscape design and detailing for the 24 rooftop gardens. This 180,000-square-foot greenroof is the second largest in the United States. Additional design features included full site hardscape inclusive of granite and bluestone plazas and walks, woodland, lakeside, and meadow trails, along with aquascape plantings around the two lakes, which serve as a key site amenity and a necessary stormwater management water quality feature due to the proximity to the Potomac River.

Cyber Park and the Institute for Advanced Learning & Technology

Danville, Virginia

A joint venture between Danville and Pittsylvania County, the new Cyber Park brings to this Southside community amenities not previously available to local and potential businesses. The new park has also stimulated economic growth in a community that has been greatly impacted by the downturn of textile and tobacco industries.

The master plan and subsequent design of the 300-acre park, including infrastructure and utilities, and programming services for a proposed 90,000-square-foot higher education center named the Institute for Advanced Learning & Technology, the cornerstone facility in the park, presented unique design considerations related to a high-tech, state-of-the-art commercial development. Situated at the corner of a major interchange, the park features broadband network access to attract high-tech industry and to support the institute. A conduit ductbank circling the park contains all telecommunication and electric lines. This design provides underground protection and a common location for all underground conductors as well as increased flexibility to add additional cabling without excavating new trenches. Restrictive covenants and landscaping plans were developed to ensure the aesthetics of the park reflect the nature of its intended occupants. A multiple server access provider (MSAP) facility houses the infrastructure that allows the park's residents to utilize their choice of communication providers.

Jack Evans Police Headquarters

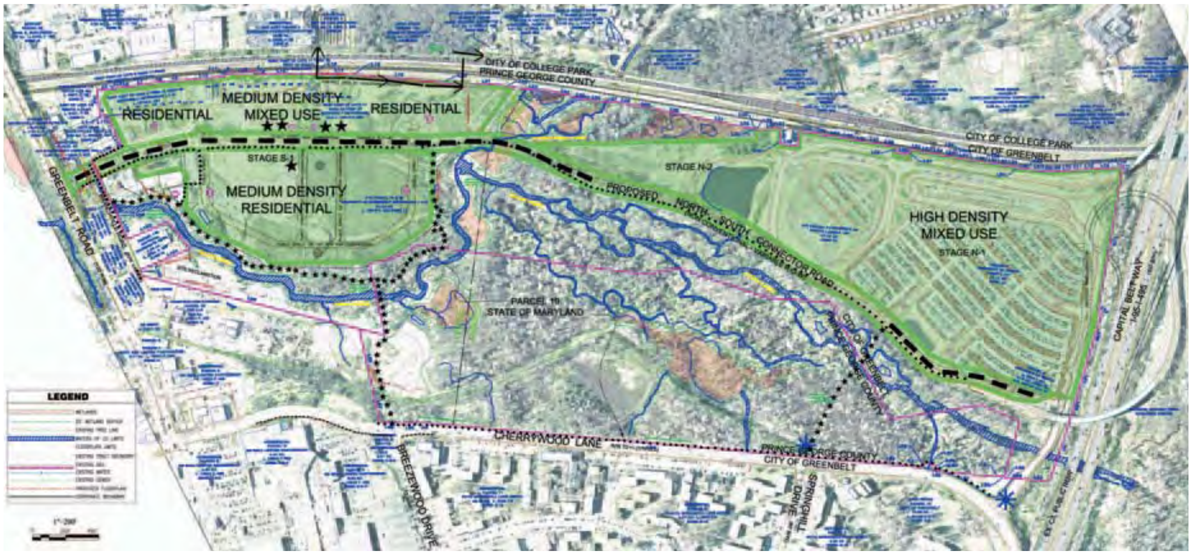
Dallas, Texas

The City of Dallas Police Department had long since outgrown its 1918 headquarters building. A comprehensive needs assessment determined that a new 352,000-square-foot building was needed to meet the police department's program needs. The city selected a brownfield site in a neglected section of Dallas on the fringe of the central business district in order to spur new development along an undeveloped corridor of blocks between the downtown proper and the site of the new police headquarters.

Beyond being a brownfield redevelopment project, the new police headquarters embraced sustainable design principles and became the first LEED® Silver building for the city of Dallas. The city configured the project site of 4.3 acres by obtaining a tract of property for the building site and then vacated one block of an adjacent public street into a private drive for enhanced security. An underutilized three-story parking garage across the street from the project site was leased by the city to meet the parking requirement of the headquarters facility. This reduced the development impact on the site, allowing more open space for public areas. The project site also took advantage of the proximity to a light rail mass transit station, one block away, for greater public access and to offer convenience and commuting options for employees. Bike racks and showers, preferred parking for carpools/vanpools, restoration of native landscaping, and 100 percent reuse of stormwater for irrigation were also achieved.

Greenbelt Station, Maryland Route 193

Greenbelt, Maryland



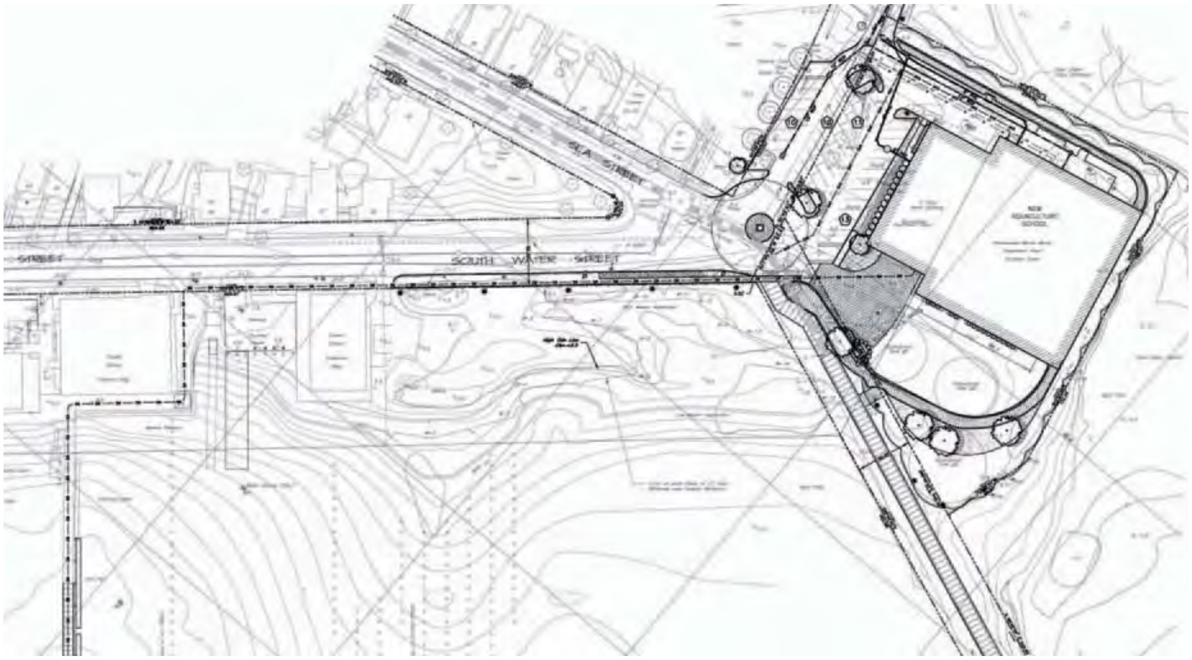
Greenbelt Station is a redeveloped quarry. It extends from Greenbelt Road (Maryland Route 193) up to the Capital Beltway (I-495) and is divided into two main areas: the south core extends from Greenbelt Road to the Narragansett Stream crossing. The north core extends from the stream crossing to the Capital Beltway and contains the Greenbelt Metro Station. This large mixed-use, transit-oriented development proposes 2250 residential units, a 300-room hotel, 1.2 million square feet of retail, and 1.2 million gross square feet of office floor area.

In conjunction with the proposed development, value engineering was required for a major connection to the Capital Beltway at the Greenbelt Metro Station, including the design of and permitting for 4400 linear feet of roadway widening and associated improvements, two major intersections, traffic control systems, retaining walls, landscaping, and utility relocations. The Branchville Bridge, an overpass directly adjacent to the site, was considered a signature site feature and was designed to enhance the overall Greenbelt Station development. As part of the project, the design team fostered an agreement between the developer and Prince George's County to mitigate all environmental impacts of the widened roadway in a major county stream restoration project within the project's watershed.

This project required multiple services including topographic and property surveys, right-of-way plat preparation, roadway and storm drain design, floodplain studies, stormwater management design, erosion and sediment control, traffic signal plans, maintenance of traffic plans, signing and pavement marking plans, landscaping plans, retaining wall and bridge structural plans, construction specifications, cost estimates, and permitting.

The Sound School Regional Vocational Aquaculture Center

New Haven, Connecticut



The city of New Haven proposed expansion of the Sound School at City Point adjacent to New Haven Harbor, a prime Long Island Sound location. The project included the reuse and transformation of the existing sewage treatment plant foundations into an expanded Regional Vocational Aquaculture Center that linked new construction with the existing Sound School located adjacent to the harbor.

Improvements included renovation of 24,000 square feet of existing buildings, the addition of a new 42,000-square-foot building, hazardous waste remediation, wetland restoration, parking improvements, and street improvements incorporating sidewalks, landscaping, and ornamental lighting. Associated with the work are several marine structures including a new 150-foot-long pier, construction of a walkway over an abandoned outfall sewer, a new all-tide boat launch, a rail-mounted boat launch and evaluation, and repair of an existing sheet pile cofferdam bulkhead.

The project began with a value engineering study balancing a wish list program against an established budget. Ultimately, the building contained classrooms, vocational shops, and laboratories. Working closely with an array of specialty consultants to accommodate a unique development program and special equipment needs, the design team was responsible for architecture; civil, structural, mechanical, electrical, geotechnical, and marine engineering; surveying, soil testing and borings; cost estimating; and value engineering.

Thomas Nelson Community College

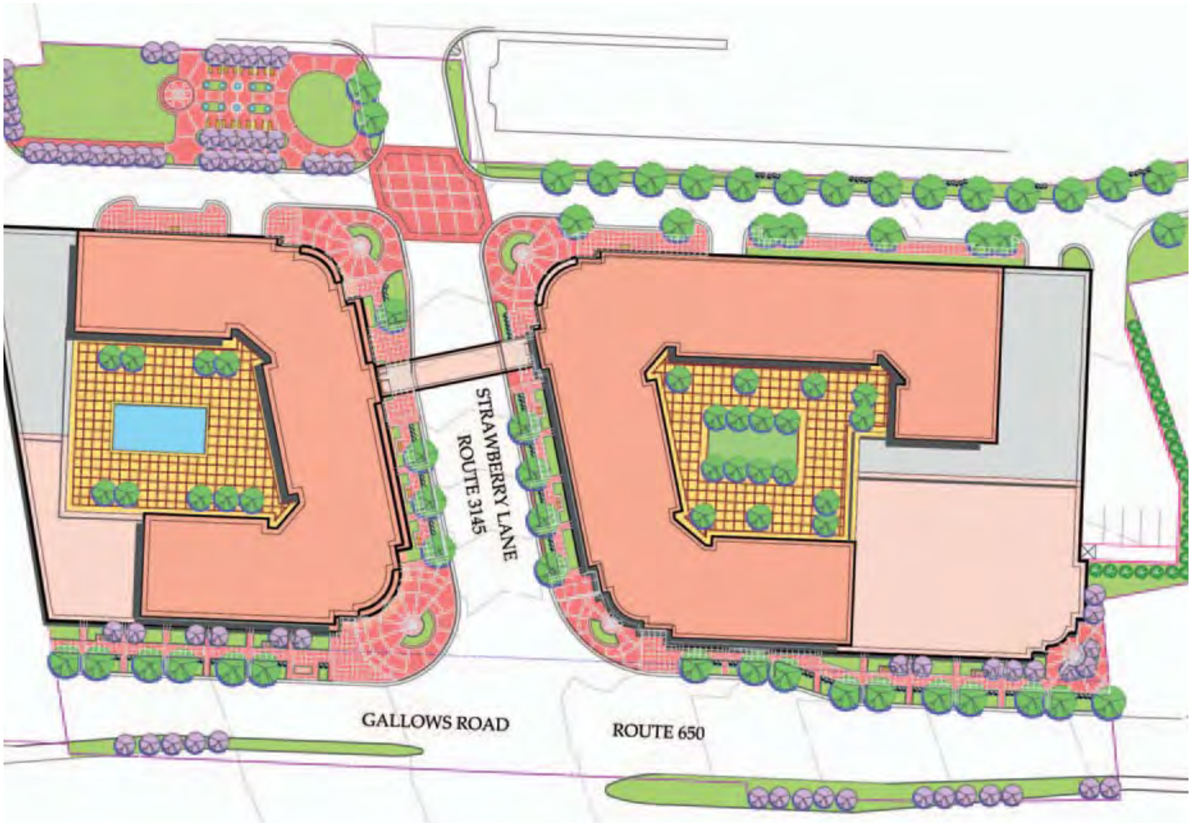
Hampton , Virginia

This Hampton Campus of the Northern Virginia Community College went through a master planning effort as part of the campus expansion. Because of its location under military flight paths, strict limitations were placed on potential building sites and heights that had to be maintained. The master planning effort also integrated additional site elements related to improved campus circulation and open-space utilization including:

- Entry gathering spots that accommodate outdoor monumental sculpture, seating/gathering spaces, and unique landscape elements
- Enhanced pedestrian circulation and outdoor gathering spaces
- Plans for a new academic student services building
- Academic buildings for science and related curriculum
- Focal points for the campus such as a clock tower centrally located on campus
- Vehicular redirection and relocation to minimize the interaction between pedestrians and traffic
- Development of multiple locations for multilevel structured parking facilities
- Additional space for academic conferences adjacent to the current workforce training center
- Creation of major campus entry elements easily seen from the access roadway and the interstate

The Vantage at Merrifield Town Center

Merrifield Community, Virginia



The 7.5-acre Merrifield Town Center property is located in the heart of the redeveloping Merrifield Community of Fairfax County and a half mile from a metro station. The flanking five-story buildings, connected via an elevated pedestrian bridge, frame the reconstruction of Strawberry Lane. Upper levels include additional retail/office space and 270 residential condominiums with rooftop open-space amenities such as intensive greenroofs, a swimming pool, and a trellis. The total building program includes 105,500 gross square feet of retail, 327,500 gross square feet of residential space, and parking for approximately 1000 vehicles. The buildings' east facade enhances Gallows Road with pedestrian walks and street-level retail. Development along the western edge provides for the transition to the developing Merrifield Town Center and includes an urban park replete with a water feature. As the first phase of redevelopment in this area, Merrifield Town Center sets the urban design precedent for continued expansion in this burgeoning community.

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