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WATER SUPPLY
FOR RURAL AREAS AND
SMALL COMMUNITIES

E. G. WAGNER

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World Health Organization

Geneva

1959

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FIFTH IMPRESSION

In this impression Annex 2 (*Conversion factors*) has been completely revised, and a number of minor corrections have been made in the body of the text; a detailed list of these changes is appended on page 339.

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Introduction

It is difficult to establish the exact degree of the importance of water to man in his arduous climb up the ladder of civilization. It is certain, however, that without water there would be no life of any kind on the earth and that, without water readily available in adequate quantity and free of pathogenic organisms, man's progress is tremendously hindered. Although no actual count is possible, billions of man-days of labour are undoubtedly lost annually because of illness and death from water-borne diseases. Unfortunately, the areas which can least afford this economic loss are the places where such sickness and death are most rampant.

The responsibility for reducing this tremendous waste falls on governments and, specifically, on health administrations. It is the aim of this monograph to assist the government officials who must meet this challenge. Among those most directly concerned are public health administrators, medical officers of health, civil or sanitary engineers engaged in public health, and sanitarians.

In an article discussing long-range planning for water service in the USA, Dr Abel Wolman of the Johns Hopkins University, Baltimore, has said: " Adequate water service, at a reasonable price, is an attainable objective. If it has not yet been attained, it is only because the skilled workers in this field have not seen fit to define the objective, to delineate the principles which should control its implementation, to devise the structure for administration and management, and to establish the fiscal principles which might safely and wisely provide the sinews for the project."[46] It has been the aim of the authors of the present monograph to consider these elements in particular relation to the establishment of services for rural areas and small communities. An effort has been made to discuss the problems of rural water-supply in a clear and realistic manner and to avoid nebulous concepts which cannot possibly apply to most of the rural underdeveloped areas of the world at the present time. On the other hand, the authors have tried to show the minimum facilities that are necessary in small communities and individual households in order to satisfy the basic personal and public health objectives of water-supply schemes.

Perhaps the most important single step in a water-supply programme is to get it started: in countries where it has been possible to get a programme under way it has invariably prospered and expanded, and the result has usually been the establishment of formal government agencies to handle

the work. It is of the utmost importance, therefore, that the best possible start be made. The authors have tried to examine critically many of the administrative as well as technical factors which contribute to successful programmes. However, it has not been possible to include in a monograph of this size all the specific information available on the various aspects of the subject. Extensive detail on many subjects has had to be omitted; but sufficient reference and bibliographical material is given to permit the health officer to seek out the necessary details should he wish to do so, and to enable the civil or sanitary engineer to develop plans and mathematical designs for water-supply installations.

The concepts presented in this monograph have evolved as a result of experience collected from many parts of the world. They are based on the firm conviction of the authors that:

(1)   in most small towns and villages in rural areas, more health benefits can be gained from money spent on a water-supply programme than in any other way;

(2)   there will be little public health benefit from a water supply which does not provide water in adequate quantity and quality and in a way convenient to the population;

(3)   the sanitary (or public health) engineer is the key element in the water programme;

(4)   health administrations should take an active interest and play an important role in the promotion, execution, and management of rural water-supply systems.

It is hoped that this document will join WHO monographs No. 31, Composting, *and No. 39,* Excreta Disposal for Rural Areas and Small Communities *as another link in the chain of efforts being developed by the World Health Organization to stimulate environmental sanitation programmes at the local level in Member States.*

A preliminary text covering certain aspects of rural water-supplies was first drafted by Mr E. G. Wagner, a short-term consultant to WHO, and was issued in 1955 as a mimeographed document. This text was circulated to forty experts in different parts of the world for their comments and suggestions. The thirty-eight replies received were much appreciated, and have been of great assistance in the amendment and revision of the original text. The World Health Organization wishes to express its gratitude to these reviewers (a list of whom will be found in Annex 1, page 255). The Organization also offers sincere thanks to the Serviço Especial de Saúde Pública of Brazil and the Institute of Inter-American Affairs, and to their staffs, for making available their vast experience, and for their frank and helpful criticism of the material.

DEVELOPMENT OF A WATER-SUPPLY PROGRAMME

Chapter 1

BASIC CONSIDERATIONS

Public Health Importance

It is difficult to imagine any clean and sanitary environment without water. Invariably, the progress of sanitation throughout the world has been closely associated with the availability of water; and, the larger the quantity and the better the quality of the water, the more rapid and extensive has been the advance of public health. The history of public health is filled with both tragic and glorious milestones in which water was the important factor.

Since all biological life is dependent on water, it must be obtained at intervals by all plants and animals, so that life develops around this need. Men built most of their early communities near the watercourses which served their economic, social, and physiological requirements. As technology developed, it became possible to transport water for physiological needs and to exploit more profitably other resources and features, such as topography, for improved community location.

Men have used water since the dawn of history; but the realization of its importance and, in some instances, of its danger, to health is a relatively recent development. Even today this knowledge is not complete, particularly with regard to the relationship which apparently exists between the quantity of water available per person and the incidence of certain communicable diseases. During the last century, water-borne epidemics and subsequent epidemiological studies focused attention on water quality and on the role of the precious liquid as an agent for the transmission of disease. Early investigations were principally concerned with cholera and typhoid fevers and, later, with all diarrhoeal diseases. More recently, increasing attention has been given to the role of water in the transmission of certain virus diseases.

Water-treatment practices for the control of bacteriological quality, begun in the late 1800's and the early part of the present century, dramatically demonstrated the need for and value of these measures. Since then, cholera has been eliminated from most countries, and typhoid is rapidly fo'lowing.

Fig. 1.   THE FIVE PRINCIPAL CAUSES OF DEATH IN CERTAIN COUNTRIES OF THE
AMERICAS, 1952 [26]

COMMUNICABLE DISEASES

■ Gastritis, enteritis, etc.

▨ Influenza and pneumonia

▦ Tuberculosis

▣ Malaria

▩ Other infective disease

OTHER CAUSES

▨ Heart and circulatory

▥ Diseases of early infancy

▣ Cancer

▦ Accidents

▣ Other cause
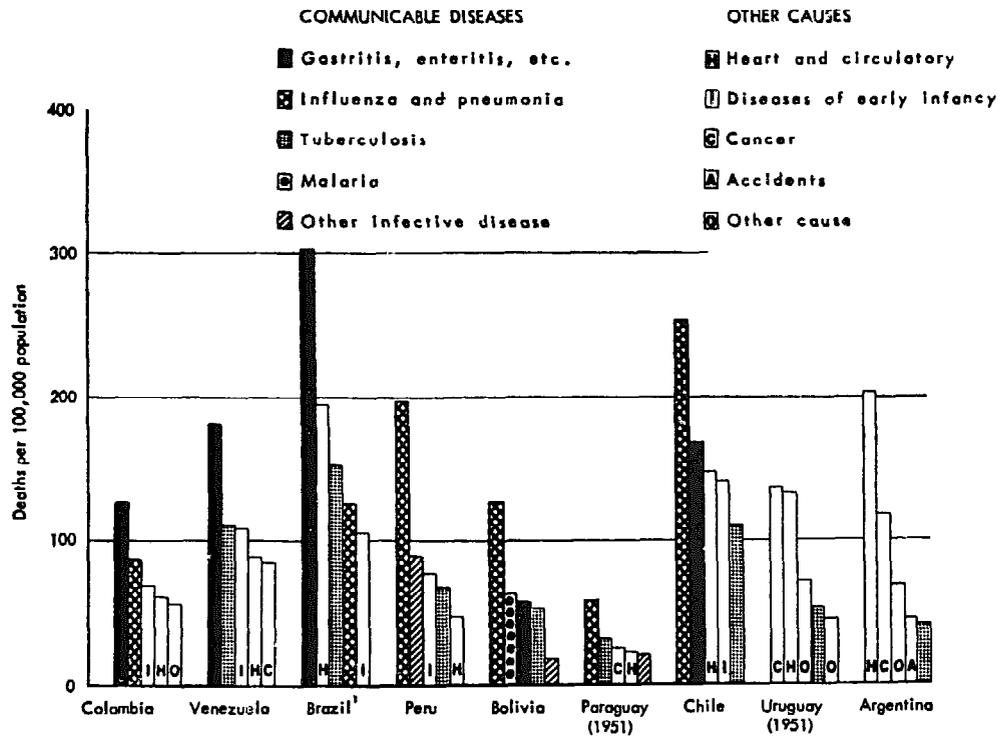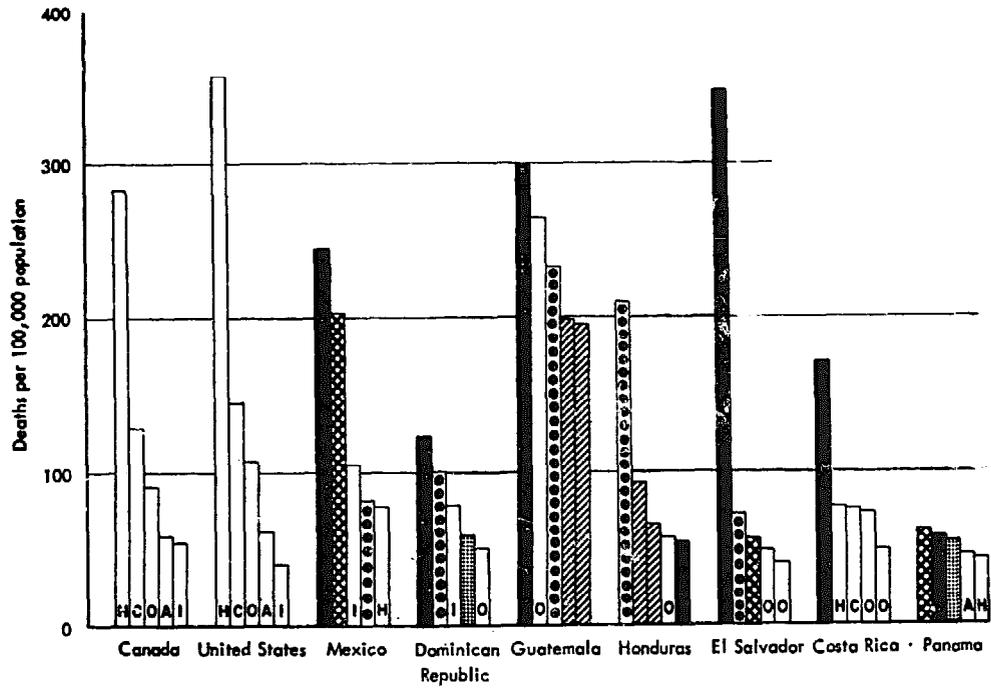
¹ Federal District and State capitals, except city of São Paulo

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TABLE I. INFANT MORTALITY AND MORTALITY FROM DIARRHOEA AND ENTERITIS FOR THE YEAR 1954 *

Country	Infant mortality		Infant diarrhoea and enteritis	
	deaths, 0-1 year, total	rate per 1000 live-births	deaths [a]	deaths from diarrhoea and enteritis(%)
Egypt	81 407	179 [b]	43 517	54.7
Colombia	48 734	103	6 277	12.8
Guatemala	14 302	88	1 392	9.7
Portugal	16 898	86	5 126	30.3
Mexico	107 853	80	21 052	19.5
Costa Rica	3 820	79	772	20.2
Puerto Rico	4 482	58	1 088	24.3
Panama	1 745	53	241	13.8
Italy	46 104	53	5 168	11.2
Uruguay	2 428	51	440	18.1
Austria	5 023	48	391	7.8
Japan	78 944	45	5 669	7.2
Germany, Federal Republic	33 353	43	443	1.3
Israel	1 417	35	198	13.9
Union of South Africa (European population)	2 298	33	277	12.0
Canada	13 841	32	554	4.0
Finland	2 750	31	199	7.2
USA	106 791	27	3 590	3.3
Denmark	2 051	27	64	3.1
Switzerland	2 280	27	42	1.8
United Kingdom of Great Britain and Northern Ireland	17 160	25	428	2.5
Norway	1 343	21	37	2.7
New Zealand (exclusive of Maoris)	968	20	17	1.7
Sweden	1 966	19	21	1.0

* Taken from *Annual Epidemiological and Vital Statistics*, 1954 [47]

[a] Figures given in this column do not include deaths due to enteric infections in the newborn (babies less than four weeks old).

[b] Figure for 1953

Water plays a predominant role in the transmission of certain enteric bacterial infections, such as typhoid and paratyphoid fevers, bacillary dysentery, and cholera. It plays a lesser role in the epidemiology of some *Salmonella* and *Shigella* infections and in amoebiasis, and has an indirect relationship in the transmission of such diseases as malaria, filariasis, and bilharziasis (schistosomiasis). Water is sometimes responsible also for the transmission of brucellosis (undulant fever), tularaemia, haemorrhagic jaundice, and several other protozoal and virus infections.

In many areas of the world the control of diarrhœal diseases continues to be a major public-health problem. Among difficulties encountered, the lack of diagnostic facilities makes specific identification almost impossible. Today, diarrhoeal diseases as a group are still the leading cause of death in many countries, as Table I and Fig. 1 reveal. Fig. 1 is based on probably the best statistical data available at present on the major causes of death in countries of which a great many can be considered to be rural in character and economically underdeveloped. This figure is the result of a special survey made by the Pan American Sanitary Organization,[26] and the data given were obtained from reports furnished by the official health agencies of the countries named. It will be noted that, in nine of the 18 countries reporting, the diarrhoeal diseases are the major cause of death, and that in three others they are the second cause. The coverage of the data is typical of that obtainable in tropical and sub-tropical underdeveloped countries, and is an indication of the best that should be expected from similar areas of the world where no comparable statistical data are actually available.

The importance of the availability of water in the control of diarrhoea has been suggested by several investigators. [22,27,42,44] Watt et al. [44] indicate that, where the risk is high, as in areas with high death-rates from diarrhoeal disease, water availability can be the most important environmental factor.

TABLE II. SHIGELLA POSITIVITY RATES ACCORDING TO WATER AVAILABILITY IN MIGRANT LABOUR CAMPS IN FRESNO COUNTY, CALIFORNIA, 1952-53 [22]

Type of water-supply facilities	Percentage of labourers positive for *Shigella*
Total camps	
Camps with water faucets inside all cabins	0.7
Mixed facility camps — cabins with inside faucet	2.7
Mixed facility camps — cabins with outside faucet	5.5
Camps with water faucets outside all cabins	7.2
Total sub-camps	
Type 1 cabins: inside water faucets and showers or toilets, or both	1.6
Type 2 cabins: inside water faucets only	3.0
Type 3 cabins: outside water faucets only	5.8
Matched sub-camps	
Type 2 cabins: inside water faucets only	1.2
Type 3 cabins: outside water faucets only	5.9

TABLE III. SUMMARY OF OBSERVATIONS ON MATCHED SUB-CAMPS FOR MIGRANT LABOURERS IN FRESNO COUNTRY, CALIFORNIA, 1952-53 [22]

	Type 2 [a]	Type 3 [a]
Sub-camps	26	26
Sub-camp surveys	58	58
Cultures	245	2147
Positive for *Shigella*	3	127
Percentage positive [b]	1.2	5.9
Average prevalence rate [c]	1.1	5.3

[a] Type 2 camps provided water from faucets inside the cabins while type 3 camps had outside faucets only.

[b] The difference between the two rates is statistically significant with $p < 0.05$.

[c] The difference between the two rates is statistically significant with $p < 0.001$.

Hollister [22] and his co-workers, in a study of migrant workers in camps in Fresno County, California, showed the significance of water availability in the control of shigellosis. The results of the study are given in Tables II and III, which indicate clearly that water availability was most important in explaining the difference in the percentage of Shigella-positive cultures among the inhabitants of the two types of cabin mentioned. Other social and economic factors were the same for both groups.

The Serviço Especial de Saúde Pública of Brazil in 1956 carried out a smaller study in Palmares, State of Pernambuco, Brazil, based on mortality from diarrhoeal diseases among infants of less than four months of age in one town in Brazil. Table IV gives the results of this study, in which (unlike the above-mentioned investigations) it was not possible to evaluate all the economic and social factors which were at work in this town. It is obvious, however, that water availability was important, a fact which agrees with Hollister's conclusion. The Brazilian study further showed that the health risk was about the same whether treated water was carried from public faucets to private houses or whether water was taken from open, unprotected wells. This would indicate that the treated water was recontaminated during transport to the houses, and that the quality of water had little influence unless the treated water was delivered within the home.

When water is available and conveniently reached by the people, the tendency is to use it in abundant quantities, as a result of which personal cleanliness is maintained. Public health officials have believed for some time that the health benefits deriving from the construction of water-supply systems are considerably reduced unless water is made readily available not only for drinking purposes but also for domestic use and the improvement of personal hygiene.

TABLE IV. PERCENTAGE OF DEATHS FROM DIARRHOEAS
AMONG INFANTS LESS THAN
FOUR MONTHS OLD ACCORDING TO WATER AVAILABILITY*

Type of water supply	% of deaths
Public water-system a	
house connexions	20.00
outside faucet less than 100 m from dwelling	57.14
outside faucet more than 100 m from dwelling	68.00
Outside, unprotected well	57.58

* Study made by the Serviço Especial de Saúde Pública, Rio de Janeiro, Brazil

a About 60% of the population is served by the public water-supply system and 40% from open, unprotected wells.

Objectives and Concepts

The objectives of any water-supply system are : (a) to supply safe and wholesome water to the users, whether these constitute a family, a group of families, or a community; (b) to supply water in adequate quantity; and (c) to make water readily available to the users, in order to encourage personal and household hygiene.

Safe and wholesome water can be defined as that which will not yield harmful effects upon consumption. Fair & Geyer [16] describe wholesome water as " (a) uncontaminated and hence unable to infect its user with a waterborne disease; (b) free from poisonous substances; (c) free from excessive amounts of mineral and organic matter ". Through many years of research and study, the characteristics of a water which satisfies the first requirement cited above—i.e., that it be safe and wholesome—have been scientifically determined. Many countries have now developed standards of water quality based on knowledge and experience and designed to protect users of public water-supplies. Moreover, the World Health Organization convened a study group to review the matter, and has recently published International Standards for Drinking-Water. [48]

Thus far, similar criteria have not been developed to evaluate the other two above-listed objectives with respect to rural water-systems. Perhaps the reason is that such criteria are much more difficult to establish, being related as they are to the incidence of diseases for which accurate statistical data are often unavailable. Water-supply design in the well-developed areas of the world is based on proven data for daily water consumption and on the principle of water distribution to virtually all homes and com-

mercial and public establishments. In rural underdeveloped areas, however, there is no established pattern of practice; and economic considerations may be the limiting factor. Under "Design" (see page 42) figures based on experience in some rural areas of the world are suggested which provide partial, but arbitrary, answers to the questions relating to suitable quantity and to proximity and convenience of water from the standpoint of public health.

It is obvious that little water will be used by people who must carry it over long distances. It has been estimated that, in rural areas of the USA, a farmer without a water system walks 120 km (75 miles) a year between his house and the hand pump situated within the farmyard at a distance of about 30 m (100 ft), carrying approximately 63 700 litres (16 817 US gal.) of water for all uses, and spending an average of 40 minutes a day in doing so. In other countries, for example in parts of Africa where surface water is scarce and ground water unobtainable, housewives spend most of their time in carrying a few litres of water in cans and jars from distant rivers and springs to their homes. Under such conditions the amount of water used is the absolute minimum required for survival. It is, by necessity, rationed for drinking purposes—little, if any, being left for maintaining the personal and household hygiene which loom so large in the epidemiology of diarrhoeal diseases.

It is necessary that every agency carrying out rural water-supply programmes should face these problems honestly. From the purely public-health point of view, there is no question but that the aim should be to supply safe and wholesome water in adequate quantity to every family in its home. This does the most to encourage the use of water for personal and home sanitation. Unfortunately, water systems based on such a concept are expensive and beyond the financial means of most rural towns and villages. The other extreme is to construct one village well or to provide one public tap or watering point. This solution, however, leaves much to be desired in fulfilling the public health objectives of the water supply. Such limited distribution makes it necessary for a majority of the people to carry water considerable distances to their homes. It thus encourages them to seek closer, perhaps polluted, water sources and to neglect the use of the safe water. This is especially true when the rural community has grown up along a stream or near a source of water which may be subject to gross contamination and pollution. Any attempt to substitute another source must involve some advantage that the inhabitants can understand easily, and the most obvious one is convenience.

The public health responsibility of an agency is not discharged merely by the installation in a community of a watering point or of a pipe in one of its streets : only when the people actually make good use of the new water-supply can the installation be counted a success. Often public health workers have been disappointed when the installation of a safe public water-

supply has not materially altered the disease picture in a community.
Close examination usually reveals that the safe water is either inadequate
in quantity or poorly located and distributed, or both, the result being
that the people continue to use a closer, contaminated source or to carry
an amount which is insufficient to encourage personal hygiene.

The decision which must be taken by the responsible agency is not an
easy one, for in almost all cases it is a compromise between economic
realities and public health necessities. If reasonably good water-distri-
bution cannot be assured, it may be doubtful that any real public health
benefit will be forthcoming. While it is true that complete distribution is
expensive and may seem beyond the possibilities of many rural communities,
a public water-supply which, because of inadequate distribution, offers
neither convenience nor health protection is even more expensive. The
expenditure of public funds for such an inadequate system can be justified
only if it is recognized as the first step towards a more complete system.
It is strongly recommended, therefore, that *long-range plans should always
provide for the distribution of water at least to points easily accessible to the
majority of the people and that, where possible, the distribution layout should
facilitate private house connexions.*

The elaboration of a rural water-supply programme involves, besides
engineering planning and design, several other considerations, among
which promotion ranks high. It is not uncommon to find that such a pro-
gramme is conceived by engineers in terms of hydraulic and structural
design and costs estimates for labour and materials. In most instances, a
concept based on the engineering approach alone is unrealistic and may
not produce the expected result, which is the construction of rural water-
supplies where these are needed. Besides the purely technical aspects
and, indeed, well before technical problems can be tackled, there is often
a need for stimulating requests by individuals, groups, and other agencies
for such a programme and for promoting the financing of the system—
in short, for " selling " the scheme. These efforts constitute perhaps one
of the most difficult phases of rural water-supply programmes and require
much time. They usually involve action by the federal or central govern-
ment, the state or provincial government concerned, the local government
or authority and, finally, the community itself. Each has its part to play
in the development of a successful project.

The Role of the Central Government and Health Administration

Experience in successful rural water-supply programmes throughout
the world indicates clearly the need for action from the highest adminis-
trative echelons of central government. The words " central government "
should be interpreted as the federal government in countries with highly

centralized administration, or as the state or provincial government in countries with decentralized administration. In either case, it is from this level that a major part of the technical and financial resources usually come for public water-supply development. The early programme concept is often the result of thinking and planning at this level of government administration. Depending upon a country's pattern of organization, the central agency responsible for the development and execution of this work will be different, being either the public works administration, the Ministry of the Interior or the local affairs department, the Ministry of Housing, or some other governmental or semi-governmental agency. But in any case, the health administration retains its responsibility for the protection of the public health. This responsibility can be discharged by the establishment of close co-operation with the agency actually carrying out the rural water-supply programme, or by the outright execution of the work by the health administration itself.

The central health administration is the most logical agency to take the lead in promoting such programmes, for several reasons :

1. There are few other investments of effort which will repay as much in health benefits as rural water-supply programmes, since an adequate and safe water-supply is a basic requirement of a healthy environment. [45, 49, a, b]

2. The provision of safe water is one of the principal environmental control measures against the transmission of most diarrhoeal diseases, which often constitute the major public-health problem in rural areas.

3. The promotion of rural water-supplies depends to a large extent on community action. Health agencies are usually experienced and equipped to foster such action and participation by the people.

4. The public works administration which normally carries out public service projects such as water supply is usually too occupied with large works to give proper attention to small, rural water-supplies. This is probably one of the chief reasons why so little has been done in this field in many countries.

5. Health aspects are often poorly understood and sometimes completely disregarded when the health administration is not intimately involved in the planning and execution of the water programme.

In most instances, the individual family or rural community can cope quite readily and relatively cheaply with its excreta- and waste-disposal problems, given limited but active educational, technical, and financial assistance. [43] The same is not true with regard to its supply of safe water. Here, the technical, administrative, and financial problems involved are more complex; and considerable assistance is required from outside.

a Wagner, E. G. & Wannoni. L. (1953) *Anticipated savings in Venezuela through the construction of safe water-supplies in the rural areas* (Unpublished working document WHO/Env.San./40)

b Atkins. C. H. (1953) *Some economic aspects of sanitation programmes in rural areas and small towns* (Unpublished working document WHO/Env.San./56)

Individual or community water-supply systems, properly designed and constructed, present difficulties that are almost always beyond the possibilities and resources of individuals to solve by themselves. In the matter of rural water-supply, therefore, more community or group action is necessary in order to search for and concentrate technical and financial resources. The central health administration should be prepared to give assistance in these problems. It can properly justify the employment of highly paid technical personnel, who will often be called for service by an increasing number of rural communities. It should also be prepared to give financial help in terms of grants or loans, as the case may be.

In many developed countries, farm credit and home improvement programmes provide a means for constructing residential water-supplies, while national loan and assistance programmes are resorted to for the solution of community water-supply problems. Experience in parts of the world shows that when the health administrations have organized themselves in such a way as to be able to give technical assistance to local communities and to promote long-range financial planning, there has been great progress in the construction of public water-supplies for small rural towns and villages. But whatever the case, the central agency concerned should organize a technical section entrusted with the definite responsibility of giving direct consultation and assistance in this field. The vast majority of small rural towns and villages, to say nothing of individuals, are unable to pay for the technical services required to make proper preliminary investigations, and to design and construct even small, simple, water-supply systems. As a matter of fact, even in those rare cases where a town can pay, it is not easy in most countries to find qualified water-supply engineers interested in the small fees involved. The agency should, therefore, provide the consulting service which is indispensable in order to start the series of events that will lead to the actual construction of proper water-supply systems. If the central administration or agency is ready to guide and assist local communities, it can often discourage them from spending money on less important projects and may help them to channel available resources into the water-supply scheme.

The agency should be prepared to make preliminary field investigations to determine the best source of water, to make topographical surveys of the town or village and its surroundings, and generally to obtain complete information upon which an accurate design could be based. Thereafter it should undertake to make detailed engineering designs and financing plans, including the preparation of all documents necessary for letting the construction by contract, if such a system is possible or desirable. After that, it should provide for the supervision of the construction work and, if required, for the execution of the work directly under its own administration. The staff and equipment necessary to carry out such work are discussed in other sections of this monograph.

Such a plan may seem at first glance to represent an extension of the work of a health administration into a field that is foreign to its normal function. It has been tried in many countries in the Americas and elsewhere, and it is believed to be a realistic approach in most countries today if progress is to be made in the development of rural water-supplies.

As already stated, in countries where the programme is under the direction of the public works or another agency, the health administration should be closely associated with this development. An agreement between the agencies should be worked out so that engineers with public health training can bring their knowledge to bear on the health aspects of water-supply projects. The health administration should :

(1) approve the final design before construction may begin;

(2) approve the construction before the project is put into operation;

(3) work out operating plans with the organization responsible for management of the water systems.

Community Participation

The local community has an important role to play in a rural water-supply programme. The community, for the purpose of the water project, may be considered to comprise (1) the local government, (2) leading citizens, (3) the religious leaders, and (4) individuals.

The local government may be elective or appointive but, in any case, it has jurisdiction over the matters which affect the community. While it is true that in many countries public improvements for rural towns and villages are decided on a higher level and that decisions are handed down, a much more successful way is to obtain full and complete co-operation from local governments directly. In the case of a water-supply programme, the task of obtaining the necessary local co-operation and participation in the development of the project should be assigned to an interested and responsible official, preferably the engineer in charge of the programme. Almost without fail local governments welcome such gestures and usually volunteer more support than their resources allow. The extent of the material support must always be soberly judged and evaluated. The important thing at the beginning is to get the official consent and co-operation of the community concerned.

Many prominent citizens may not be members of the local administration; but, at the same time, they may bring even more influence to bear on the success of the proposed water-supply programme than does the official administration. It is not uncommon to find that community leaders are outside the government. Such persons should be brought into the planning of the scheme. They need to understand and support the project and therefore must be approached with tact. Religious leaders in many

communities are highly important and often cultured people who can appreciate the value of such a project and who may give vital support.

The people of the community must be given some understanding of the need for safe and wholesome water and of the part which the water-supply project will play towards filling that need. The enlistment of the support of the local government and community leaders will help to attain this end. In general, health education techniques, applied at the earliest planning stages and preferably under the guidance of a professional health educator, will be of great value in marshalling public support for the rural water-supply programme.

The various population components of the community (i.e., government leaders, community leaders, religious leaders, and the public), usually will not each back the project to the same extent : certain groups or individuals may be seeking personal advantage, but if the majority can be persuaded on the basis of one or another aspect of the scheme, full community support will be the result which, in fact, is the desired objective. The manifestations of this may be many, and may include :

(1) the mobilization of political support at the local, provincial, or central level;

(2) the contributions of the community to the project in terms of money, land, materials, services, or labour;

(3) a more sympathetic attitude from the people towards paying for the operation and maintenance of the water system;

(4) the increased use of the water once it is supplied.

The Role of the Sanitary Engineer

As pointed out by Wagner & Lanoix in their monograph *Excreta Disposal in Rural Areas and Small Communities*,[43] it is quite probable that rural sanitation work has been carried out in many parts of the world without sanitary engineers, but not without sanitary engineering. Experience has repeatedly shown that in environmental sanitation work in general, and in rural water-supply in particular, engineers trained in the sanitary sciences are needed at the highest possible level of the health services for the formulation, administration, and development of suitable programmes.

In order to avoid misunderstanding, it might be well to define here what is meant by the terms " sanitary engineer " and " sanitary engineering ". The following definitions, adopted in 1955 by the American Public Health Association, [1] have received general acceptance : The term sanitary or public health engineer "... refers to the engineer who is trained in techniques that permit him to advise upon, administer, supervise, or otherwise conduct professional and scientific work where the use of engineering knowledge

and skills are essential for identification and control of environmental factors that may produce a detrimental effect on the physical, mental, or social well-being of man ". The term sanitary or public health engineering "... includes the public health aspects of all environmental conditions and situations, the control of which is based upon engineering principles and the application of scientific knowledge ".

The WHO Expert Committee on Environmental Sanitation[49] stated in 1953 : " Responsibility for environmental sanitation programmes should be borne by the head of an organization who is advised by, and has at his disposal the services of, suitably qualified medical and engineering staff. The committee therefore strongly recommends the inclusion of sanitary engineers at a proper level in the national health structure to fulfil this function ".

From the above opinions, the role of the sanitary (or public health) engineer in the planning, organization, and execution of rural water-supply programmes can be clearly seen. His training and interests designate him:

(1) the logical person to stimulate, conceive, and develop plans based on epidemiological facts and statistical data and presented in a way that health and other government officials can understand and appreciate;

(2) the specialist with the indispensable knowledge for the study, design, construction, and operation of water-supply systems, large or small;

(3) the adviser to local communities in the inevitable problems of management of rural systems.

It is also the duty of such an engineer to advise the chief medical officer of the health administration on the approval—from the sanitary standpoint —of all plans for water-supply development or extension, irrespective of which government administration or private agency may be responsible for such plans (see page 23). In so doing he will ensure that these plans satisfy basic health requirements and that the structures involved are of simple design and are easy to maintain by the rural communities concerned. He will be responsible for the development of guides and manuals for use by individuals, local construction foremen, and water-supply operators, and for the establishment of design criteria and minimum standards suitable for sanitary practice in the country's rural areas. As a member of the public health team, his work will be closely integrated with other medical activities (communicable diseases control, school health, maternal and child health, etc.) carried out within or outside the health administration.

Chapter 2

PLANNING

Personnel Preparation and Training

Categories

The proper planning, implementation, and management of water-supply systems depend principally on the availability of competent personnel. The leader in this work must be an engineer, preferably a sanitary engineer, who is trained for the technical tasks involved and is experienced in the field of public health planning and administration. To be most effective in a health administration, the engineer must be familiar with the broad principles and aspects of public health and the relation of engineering to them. His understanding must extend, furthermore, into the area of general economic and social development of which public health and sanitation are a part. The third report of the WHO Expert Committee on Environmental Sanitation [49] correctly points out that environmental sanitation programmes should be integrated with other community programmes and in phase with the general progress and needs.

To assist the engineer in the implementation of a rural water-supply programme, competent sub-professional assistants are needed. These will include :

(1) foremen of the labour crews which carry out innumerable tasks involved in investigations, construction, and operation of water supplies;

(2) topographers to make the necessary land surveys upon which design and plans are based;

(3) draftsmen and calculators to draw the plans and make the calculations, under engineering supervision;

(4) waterworks operators to keep the systems running properly.

Training

Training for personnel concerned with rural water-supplies may be divided into : (a) professional academic training, (b) observation visits, (c) short special courses (usually in-service type), and (d) supervised experience.

Professional academic training is almost exclusively for the engineers and may be obtained in several countries. Petrik[30] lists five schools in Europe and 13 in the USA offering post-graduate courses in sanitary engineering. There are also engineering schools in other countries offering courses on the graduate level. While most of these are based on one academic year (nine to ten months), it is often possible to take special work for shorter periods.

Observation visits to outside areas or other countries to see the development of similar programmes can be profitable to all categories of personnel. Usually each country develops its own methods and system to deal with such schemes, and there is always something new to be discovered by an outsider. Such training must be well organized and planned from the point of view of both the visitor and the host. Where detailed arrangements are not planned in advance, a considerable amount of time is lost, and visitors often fail to get full benefit of the opportunity. This type of training has been applied extensively to professional public-health workers, but it can be very useful for sub-professionals as well. When given the opportunity, technicians will invariably discuss their mutual problems in great detail and with benefit to all.

Short courses can be designed for all categories of personnel, but have been widely used to train sub-professional persons to do specific jobs. In relation to rural water-supplies, such courses can be especially useful in improving the knowledge of existing staff in important fields. Operation procedures in water systems and equipment maintenance are specific examples of fields in which short courses have been very successful.

Supervised experience applies to all and cannot be overemphasized. Building up the staff by offers of progressive appointments and of increasingly important responsibilities is the surest way to success. Good supervision is a combination of leadership, on-the-job training, and discipline, and can be used to gain outstanding performance by the programme's staff. Too often, however, supervision is thought of in the disciplinary sense, and consists of nothing more than keeping an account of the time an employee spends on the job, seeing that he does at least the minimum tasks, and paying him. Government agencies are notoriously lax in taking advantage of the opportunity for developing staff through supervisory leadership. Outstanding and successful organizations, whether public or private, never fail to make the most of such opportunities by helping staff members to improve and augment their technical knowledge through training programmes and good supervision.

In most of the countries where the greatest need exists for rural water-supplies, there is a most acute shortage of qualified technicians. The responsible administrations therefore need to make strong efforts and to use every opportunity to train and develop the necessary technical staff.

Financial Planning

General

Plans for financing rural water-supply programmes can best be developed by officials who have the most knowledge and experience of such work —the sanitary (public health) engineers and public health officials. If these individuals who have a primary interest in this work do not take the lead in promoting and developing financial plans, little in the way of execution is apt to be accomplished.

The stock reply to questions about financing is that the country, state, province, or community concerned is too poor to afford the cost of needed improvements. Upon investigation, however, it often turns out that public money is being spent for projects which are of much less importance and which cannot possibly give the same returns as those obtained when the same amount of funds is invested in the construction of public water-supplies. There is usually a way to obtain long-range financing for rural water-supply programmes if the individuals concerned with the problem will look far enough for a good case to present to their legislators or to financial institutions. Long-range plans have been effective in many countries throughout the world, both in the Western and Eastern Hemispheres. Most of them are the result of the work of a few people who have succeeded, after painstaking efforts, in convincing the right government or bank of the importance of sanitation work.

In almost all successful programmes, federal or central governments have shouldered the responsibility for financing the construction of small rural water projects. Because of the lack of credit on the part of most rural towns and villages and the absence of a system of financing public works through direct loans from private banking institutions, the central government must usually fill the role of provider of funds. In some places the states or provinces co-operate. The use of revenue bonds, which is common in countries such as the USA, for the financing of waterworks is seldom applied elsewhere. In many countries, the normal pattern is for the central government to loan the necessary funds directly to a local community at a low rate of interest or to make a partial grant, with the community, or community and state jointly, supplying the remainder. Loans or grants are made on the basis of projects presented by private engineering firms through proper channels for approval by state or federal engineers, or of projects presented directly by official technical administrations competent to study and design waterworks. The latter is the more common pattern for the smaller towns in rural areas since they are usually unable to pay for the services of engineering firms competent to do the design work. A sanitary engineering section in a central health department would be qualified to provide this technical service to rural communities.

In some plans money can be borrowed for the purpose of making studies and designs; but this is not common practice, especially in the case of small communities. Construction of small works is usually carried out directly by the technical water-supply agency of the government, either federal or state. Projects for rural communities are limited in scope; and yet many unforeseen elements and technical difficulties are likely to crop up in the course of construction, causing appreciable increases in the original and budgeted cost. Because of this, contractors are forced to bid very high to be on the safe side. In cases where projects are let out by contract, the government's technical water-supply agency does the inspecting and generally looks out for the interests of the local community. The actual awarding of the contract is usually a function of this agency.

In many financing plans the community is expected to contribute labour, land, local materials, and some services to the project, because these may be easily obtained locally and are often very reasonable in cost to the community. As a matter of fact, where the town or village is receiving a grant, it should at least be required to contribute those things that are available locally. Such a system offers an excellent opportunity for a government health administration to work with a local community on a co-operative basis, making full use of local resources to further the public health. It also helps to foster in the community a sense of ownership and pride in something which its members had to toil hard to achieve.

Co-operative projects are not always appreciated by government administrations, which often fail to understand their great advantages and significance from the standpoint of public relations and interest. It is true that such projects are slow of execution and that great patience and tact are demanded if they are to be carried through to successful conclusion. However, they are indispensable when large numbers of community water-supplies are to be constructed in areas of poor economic possibilities. In some areas original cost estimates of new water-systems have been reduced by as much as 50% because the local people were able to furnish all the unskilled labour as well as services such as transportation, office space, warehouses, etc., plus all the local materials required. Naturally, the technical supervision was provided from higher administrative echelons.

Thus health administrations, by taking the initiative, can successfully, over a period of years, accomplish a great deal in the realm of rural water-supply development.

Revolving funds

While it may not be possible in every country to develop financing plans based on reimbursable loans, such plans should be given careful consideration. The use of revolving funds is an excellent system which may be

applied to the development of water supplies for rural areas and small communities.   In this system each unit of money can be used over and over to provide needed facilities, while on the contrary direct grants can be used only once.   Furthermore, when a community wants a water system badly enough to pay for it, there is every possibility that the works will be used and maintained properly.

Walter R. Sanches,[a] Chief Engineer and Assistant Chief of the Servico Especial de Saúde Pública of Brazil, has recently developed an excellent plan for his country.   It is based on annual grants by the Federal Government of Brazil to a fund which, in turn, will be loaned to municipalities without interest.   The federal grants will be about equal to the government's present annual expenditures, which are scattered piecemeal over the whole country by eight different agencies and which are completely uncoordinated and unplanned, as a result of which relatively little work is accomplished considering the size of the grants.   It is expected that, by proper planning, this same money—supplemented by returns from the municipalities benefited — will bring about the following results :

1.   The Federal Government will maintain its annual expenditure at the present level.

2.   Fifty-six municipalities will be granted interest-free loans in the first year of the plan and will begin to repay the following year.

3.   After six years the credits available from the annual federal grant and repayments of loans will allow for loans to 96 new towns each year until the water-supply requirements of 1774 municipalities in Brazil have been satisfied.

4.   At the end of the period when new loan requests begin to fall off, the capital fund may be used to finance extensions and improvements of water systems.

5.   The amount loaned per town is limited to an equivalent of US $70 000.   This is estimated to be sufficient for the great majority of towns needing financial assistance.   Towns requiring more capital funds may obtain the remainder from other sources.

Costs in various countries

Financial planning must be based on accurate cost data, which are usually not available in remote country districts where, often, water-supply systems are to be built for the first time.   In such instances, data from other countries could be helpful; while they are never directly applicable, they might give an idea of the costs which should be expected.

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a Sanches, W. R. (1956) *Construction of water supplies in small communities : methods of financing* (Unpublished working document WHO/Env.San./95

Pachon-Rojas [a] reports the following costs on 140 collective water-systems built by the National Federation of Coffee Growers (NFCG) in Colombia from 1943 to 1953 :

Population served	60 000, in about 10 000 farms and villages
Average cost per system	12 000 pesos [b]
Cost per linear metre of main and secondary piping	3.80 — 5.70 pesos
Cost per farm served	175 — 735 pesos
Cost per person served	55 — 95 pesos
Average contribution of NFCG to projects	71 %
Average contribution of communities to projects	29 %

Breakdown of cost :

Labour	25 %
Materials	70 %
Transportation	5 %

Also reported is the cost of 690 individual installations completed in 1952 at a unit cost of from 650 to 935 pesos per system. These installations usually consisted of a well, pump, piping to house, and storage tank.

The Pan American Sanitary Organization [c] reported in 1956 the following cost data in US dollars :

	Estimated per caput cost of urban water-supply US$	Estimated per caput cost of rural water-supply US$
Bolivia		6.10
Brazil	6.20	
Chile		6.60
Colombia	23.80	* { 13.80 { 2.35
Costa Rica	7.80	
Dominican Republic		* { 6.60 { 1.10
Mexico	16.00	16.00
Venezuela	22.00	7.90

* On the basis of population served : from various sources

Sanches [d] reports that the cost of water systems in Brazil, which include treated source or wells, pumping, distribution, and storage, is roughly

[a] Pachon-Rojas, L. (1953) *Water-supply systems for rural areas and small communities, with special reference to Colombian experience* (Unpublished working document WHO/Env.San./61)

[b] One peso = US $0.40.

[c] Pan American Sanitary Bureau (1956) *Potential expansion for health programs in the Americas through the Pan American Sanitary Organization* (Unpublished document OAS Study III), Washington, p. 55

[d] Sanches, W. R. (1956) *Construction of water supplies in small communities : methods of financing* (Unpublished working document WHO/Env. San. /95), Geneva

1000 cruzeiros per person (approximately US $17.00 for the period covered).

Basic studies on financing

An effective way to demonstrate the benefits of water supplies to government officials and lay people in general who are not acquainted with the subject is to evaluate the cost of sickness that can be reduced or eliminated through satisfactory improvement of drinking-water quality. Many studies of this kind have been done. Winslow's monograph *The cost of sickness and the price of health*[45] has been widely quoted in this respect. Wagner & Wannoni[a] and Atkins[b] developed data specifically designed to show the economic advantages of reducing morbidity and mortality through investments in water-supply systems. The former authors stated with regard to conditions in Venezuela in 1944 :

" The total annual cost in sickness and death from water-borne diseases and the actual money outlay to buy water from vendors or the outlay of time to carry contaminated water from streams to other sources is Bs. 202,991,814. Compared to this, it would cost only Bs. 21,939,750 per year to provide a safe, adequate, public water-supply to two million people; and such a programme would eliminate at least 75% of the sickness and death due to water-borne diseases as well as eliminate completely the enormous sums paid to obtain water from other sources. This is a saving—and a national economy— of Bs. 148,554,410 ($44,610,000).

" By employing Bs. 21,939,750 per year in the amortization and operation of water-supply systems, the nation can save Bs. 170,494,160 annually. In other words, solely from the economical point of view and disregarding completely the human aspect, there is a return of Bs. 8.00 for every one invested. At the same time, the amount of water supplied per head is increased from 10 to 74 litres.

" This a phenomenal national investment opportunity to obtain an 800% annual return on the capital invested and, at the same time, to give two million people in rural areas seven times the amount of water they have had previously."

In Table V Atkins gives some interesting calculations based on the cost of sickness as compared to the cost of sanitary works. This table shows that from a financial point of view an investment in water supplies in all countries except the USA and France is an excellent one. Any investor would be anxious to find an opportunity which would return the invested capital in from two to five years.

The high cost of disease and death, the relatively low cost of water systems, and the savings resulting from proper use of funds are factors which public

[a] Wagner. E. G. & Wannoni. L. (1953) *Anticipated savings in Venezuela through the construction of safe water-supplies in rural areas* (Unpublished working document WHO/Env.San./40)

[b] Atkins. C. H. (1953) *Some economic aspects of sanitation programmes in rural areas and small communities* (Unpublished working document WHO/Env.San./56)

TABLE V. ESTIMATED PER CAPUT COST OF RURAL WATER-SUPPLIES AND LATRINES AND COST OF TYPHOID FEVER AND OF DIARRHOEA AND ENTERITIS PER 100 000 POPULATION FOR CERTAIN COUNTRIES IN 1949

Country	Cost per caput of water supplies (US $) a		Cost per caput of latrines (US $) a		Total cost per 100 000 population (US $)	Cost of typhoid fever and of diarrhoea and enteritis per 100 000 population (US $)	Approximate number of years required for amortization of water supply and sanitation facilities from savings
	capital cost	main-tenance	capital cost	main-tenance			
USA	17.00	0.55	14.00	5.57	3 730 000	55 720	68
France	5.25	0.17	4.35	1.80	1 157 000	73 000	16
Portugal	1.65	0.05	1.35	0.55	360 000	191 230	2
Japan	1.15	0.04	0.95	0.40	254 000	57 750	5
Colombia	2.35	0.08	1.95	0.80	518 000	195 775	3
Ceylon	0.98	0.03	0.80	0.33	214 000	49 130	4
Dominican Republic	1.10	0.04	0.94	0.38	246 000	86 900	3
India	0.63	0.02	0.52	0.21	138 000	58 265	3

a This includes the cost of labour, materials, and equipment. These costs could be reduced considerably by the use of voluntary labour and materials available locally to the householder.

officials often can and do appreciate. Such are the tools which sanitary engineers and health administrators can use to promote necessary financing for rural water-supply programmes.

Water-Supply Policy

General

With the launching of a rural water-supply programme, it is essential that the control agency, preferably the health administration, should develop a water-supply policy which will serve as a guide to engineers and others working in the programme. The establishment of general rules and lines of action is especially important in view of the usually limited funds available both for construction and for maintenance and operation.

A water-supply policy will normally deal with the types of individual projects and of co-ordinated schemes which the control agency may approve and encourage. As a general rule, no plan should be approved which involves complicated and expensive water-supply designs, treatment processes, and equipment. Any features or elements that would tax the economic and technical resources of the community beyond its normal possibilities should not be considered, because to do so is to invite disaster. All over the world one can find idle and ruined sanitary works that are monuments to planners who failed to understand and to abide by this concept. This rule is often difficult to follow and calls for hard decisions

on the part of engineer-designers, promoters of the water systems, and the people themselves, most of whom are likely to demand the best and most modern design and equipment. However, decisions must be carefully weighed, and it is usually better to do nothing than to attempt solutions that require economic or technical miracles for the success of a project. A fundamental aim should be to supply safe and wholesome water, distributed as widely as possible for the least initial cost and through a system that requires a minimum of maintenance. The control agency, which also may be involved in the design and construction of the necessary works, should insist upon the necessity of carrying out an extensive preliminary search for a water source that will fit this aim. This generalization is elaborated further in succeeding paragraphs to show how the principle may be used in practice.

It should also be the policy of the control agency to co-ordinate the requests of neighbouring rural communities for water-supply schemes. Through the incorporation of water districts, it has been found advantageous in many countries of Western Europe and in America to provide ample and safe water to groups of rural towns and villages at greatly reduced cost to all concerned. This is especially true when water needs to be conveyed by gravity from distant sources through long supply pipes which may cross or pass by several other villages.

Source and treatment

First-priority consideration

Water which requires no treatment to meet bacteriological, physical, and chemical requirements [a] and which can be delivered to the consumer by a gravity system should be given first consideration. This would usually be limited to springs and protected drainage areas. Such a system requires no treatment and no pumping and, therefore, is ideal from the point of view of maintenance, which is thus reduced to an absolute minimum.

Second-priority consideration

Water which requires no treatment to meet bacteriological, physical, and chemical requirements but which must be pumped to consumers would be the second choice. Well supplies would fall within this category.

Pumping can be an economical and simple solution, but it can also be an expensive and complicated one, according to local circumstances. It depends on the availability of qualified operators and on the local cost of fuel. Such factors vary widely from country to country and even from one rural area to another of a given country; they vary also with the types

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[a] These requirements depend on water quality standards applied by each country, and will vary from one place to another.

and efficiency of operation and maintenance programmes developed for providing aid to municipalities from centrally located headquarters.

Third-priority consideration [a]

Water which requires simple treatment before it can meet bacteriological, physical, or chemical requirements but which can be delivered to the consumer through a gravity system should be given third-priority consideration. Simple treatment is considered to be limited to : (1) storage which would provide plain sedimentation and some reduction in bacteria, (2) chlorination without the use of a mechanically operated chlorinator, (3) slow sand filtration; or a combination of these.

For rural areas this is normally an inferior solution. It is usually more expensive than the above solutions and involves operational procedures which are most difficult to maintain in small rural communities. In such places, when the chlorine stock runs out, chlorination is abandoned in almost every instance; and, when the slow sand filters become clogged, a by-pass is often considered an easy arrangement. Such is the history of treatment measures in most rural areas where routine technical assistance is not provided by a responsible agency.

Fourth-priority consideration

Water which requires simple treatment, as mentioned above, and which must be delivered to the consumers by pumping would obviously be the most expensive choice to make.

Distribution and storage

In most treatises on urban water-supply, complete distribution is taken as a matter of course since a large percentage of house-owners, communal establishments, and industry are vitally concerned and are expected to contribute the largest share of the capital investment involved. In rural water-supplies, however, distribution is considered from a different point of view. As indicated before, one important reason for promoting the construction of rural supplies is the provision of safe water in adequate quantity and in a convenient way to villagers in order to improve rural health. The consideration of health benefits then assumes major importance. If attention is not given to proper distribution of the water, the primordial health objective may be lost. Plans which provide for the construction of a central village well or tap should be considered only as a first step towards complete water distribution. The health administration should continuously urge the amendment and extension of such

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[a] Depending on local circumstances, this could be a second priority.

systems wherever they exist in the country; and, as previously stated, it should assume leadership in promoting and constructing the necessary improvements.

Considerations regarding storage follow the same logic. Storage is a measure which contributes to safeguarding water quality. It is necessary for the supply of peak demands which occur in all systems, whether a simple village well or a large city supply. Storage is most needed where one or two hand pumpers supply a relatively large number of people from a single well. Pumpers can work more or less continuously and thus extend the utility of this minimum facility.

Preliminary Investigation

General

Preliminary field studies and investigations are part of the duty of the engineer, who must possess, besides technical competence, diplomatic and persuasive ability to stimulate a strong interest among the members of the local community for the proposed project. The problems involved in these studies are in many ways as complex as those found in large, municipal, water-supply schemes. This stems from the fact that in developing the project the engineer must always compromise to a varying degree with regard to established standards of water quantity and quality. He is likely to be confronted with a great range of solutions between what he knows to be desirable and what appears to be possible. He must be careful not to produce either a fine project that is unrealistic or a realistic project which is completely inadequate from the point of view of the fundamental objectives previously discussed. He must explore every technically feasible scheme and must strive to find a sound and economical solution, at the same time persuading the members of the community that it is in their interest to marshal funds for the water-supply project.

A thorough and conscientious field investigation for a water supply is usually time-consuming and expensive, but it is one of the most important phases of the whole undertaking. An error at this stage can plague the entire operation of the project and, as history shows, can later cause irreparable damage to the water system or result in its total failure. On the other hand, it is in this phase that, by careful work, great savings can be effected, not only in original cost, but also in future operation and maintenance of the system.

Field equipment

The engineer should be prepared at the outset of his investigations to determine the quantity and quality of water available from any possible source. He must therefore take along with him, or he should be able

Fig. 2.   SIMPLE WATER-PROSPECTING EQUIPMENT *

A = Tripod
B = Sheave wheel
C = Rope
D = To motor winch
E = Drive hammer
F = Jar length
G = Drive head
H = Rod coupling
I = Drill rod
J = Casing
K = Chopping bit (This may
       be replaced with a
       sampler if desired
       The water swivel is
       then replaced by a
       rod drive head.)

L = Casing drive head
M = Rod drive head
N = Casing drive shoe
O = Lifting bail
P = Water swivel
Q = Pump
R = Suction hose
S = Tank
T = Tee, replaced by drive
       head when driving
       casing

* Both illustrations show simple equipment for making exploratory holes. Casing is driven into water-bearing formation, and cuttings are washed out.   Undisturbed samples can be taken at necessary intervals.

Well screens may be set in holes for test pumping when desirable.

Fig. 2. SIMPLE WATER-PROSPECTING EQUIPMENT (continued)

a = Derrick, 4 legs of pipe
c = Rope
e = Weight for driving drill
    rods when wash point is
    replaced by sampling
    spoon. Larger weight
    used for driving casing
j = Casing

k = Chopping bit, replaced by
    sampling spoon during
    sampling operations
p = Swivel
q = Pump
r = Suction hose
t = Tee, replaced by driving
    head when driving casing
z = Wash pipe (drill rods)

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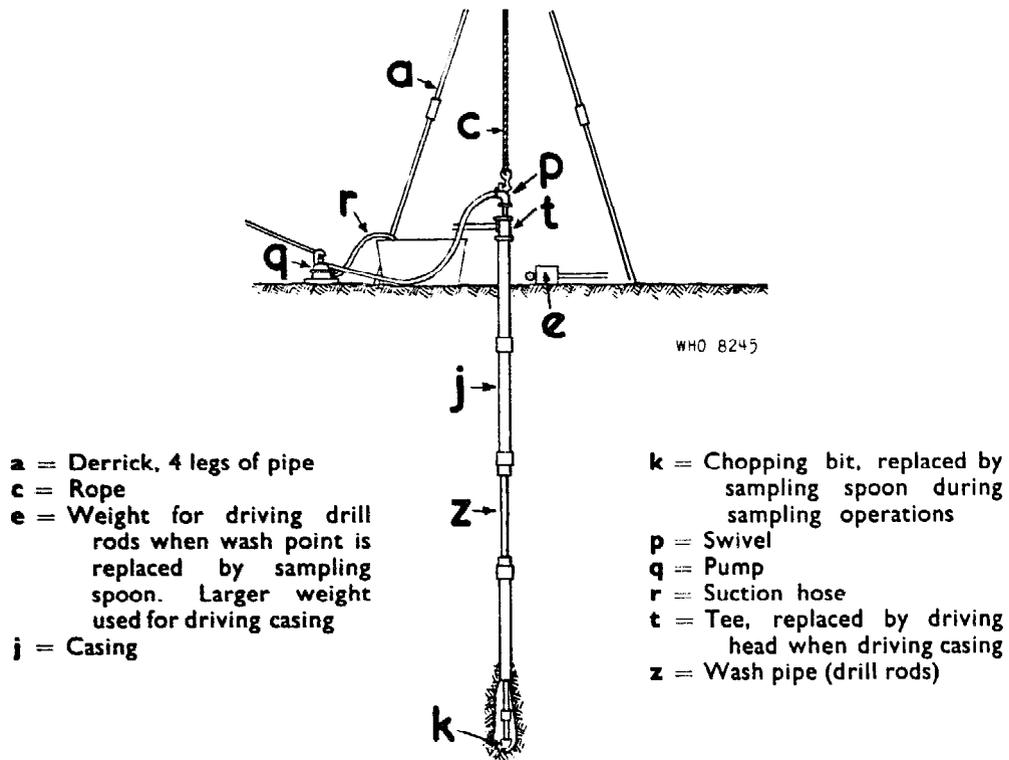
to obtain quickly, equipment necessary for exploring either ground or surface water. Such equipment might include the following :

Jetting equipment
Boring equipment
Drilling equipment
Chemical water analysis kit
Bacteriological water analysis kit
Barometer for measuring difference in ground elevation
Pedometer for measuring distances roughly
Weir for measuring stream flow
Surveying instruments for topographic survey
Transportation equipment
Pumps for testing the yield of available water sources.

The equipment for making exploratory investigations can be elaborate or simple, depending on the accessibility of the area to be explored and the amount and reliability of basic information already available (see Fig. 2).

Field work

The engineer in charge of this work should remember that the first order of business upon his arrival in a community is to make the proper presentation to the local officials (see " Community participation ", page 23). Too often valuable support is lost because the technicians deputized from a higher level of government pay little or no regard to local authorities. This is always a grave mistake, and has caused more than one project to be delayed many years. The intricacies of local politics should not be ignored or overlooked, but the engineer should keep himself free from all sides and should endeavour to win the combined support of all parties. Admittedly this is not an easy task, but it is a highly important one. He should also make it clear to the local authorities and population that his work will consist of a preliminary survey only, and that a water-supply installation is not to be expected immediately after this survey.

General information about the economic and social life of the community, such as data on income, expenditure, produce, tax rates, etc., is necessary for the preparation of the engineer's report. He should, before leaving the town, obtain a complete record of local resources and evaluate, with the help of the officials, the community's probable contribution to the project in terms of materials and services. A topographic map, which might be made at the same time or at a later date, should indicate the location of all houses, schools, markets, hospitals, health centres, important public buildings, and any other institutions which would require special consideration from the point of view of the water system. If a census is not available, it may be convenient to make one along with the topographic survey.

Any geological and rainfall data pertaining to the area should have been studied beforehand, or at least should be available for consultation at the time of the preliminary field study. This information will bear on any decision regarding a particular source of water. If the town is situated in a hilly or mountainous region, there is often a possibility of finding a spring or stream coming from a protected drainage area above the town which can serve as a source of supply. Local people are usually willing and anxious to serve as guides. Any information they give should be carefully checked. The engineer should examine carefully every possible source from the standpoint of the quantity of water which it will yield. A weir will serve to measure the flow and, along with information from local residents and rainfall data, will enable him to judge the adequacy of surface sources as well as the fluctuations of their yield. Needless to say, the low water flow is the important and decisive factor. It usually pays to bring pre-cut weirs of metal or wood which can be fitted into locally built dikes.

A pedometer and barometer will help the engineer in obtaining a closely approximate idea of the distance and altitude of any water source for preliminary consideration. Distances and ground elevation must, of course, be measured accurately for final design needs.

If the topography of a particular area is flat, or if a thorough search reveals no satisfactory source from which water could be supplied by gravity, then a ground-water investigation becomes necessary. Since funds for rural water projects are usually very limited, a ground-water source should be developed as close as possible to the centre of consumption and yet be located so as to be protected from any underground contamination.

A survey of existing wells in the town will be a good starting-point in the effort to determine the possibilities of supply from ground water. The history of these wells will provide an indication as to the fluctuations of the water table during past seasons and years. Usually people will recall the extent of fall during periods of maximum drought. The amount of water that is being drawn from these wells and the rate of recovery of the water table are indicative of the capacity of the water-bearing stratum. Often it is possible to test the yield of some of the wells by pumping, and to analyse their water for physical and chemical quality. Experience shows that, where there is a difference in water quality among wells in a town, as is often the case, the local population will quickly single out the well which yields the softer, better-tasting water; but it should be remembered that this better-tasting water is not necessarily the purest source.

A study of available geological data (where such data exist) in relation to the profiles of deep drilled wells or test borings may prove to be extremely useful.

Very often sand and gravel deposits can be found near streams and rivers by making systematic borings along the banks with augers or by jetting. In any case, when a likely spot is selected, a test well should be put down in order to determine with reasonable accuracy the possibilities of constructing a permanent supply well later. The test well either can be built of a small-size pipe for a mere study of the characteristics of the underground strata, or can be made of larger-diameter pipe which can later be developed (when possible) into a producing well.

The type of casing used depends on local circumstances. If there is sufficient evidence to indicate that a good water-bearing formation may be found, the use of a larger casing which could later serve for the finished well is a justifiable risk. Where the chances are slim, a 4- to 5- cm (1½- to 2-in.), jetted, exploratory well might be a better choice. Furthermore, when the objective of the field investigation is only to explore and determine the possibilities of eventually constructing a producing well, there would

be no justification for putting in a large permanent casing which would serve no future purpose.

The engineer should also examine each possible source for chemical quality. A field chemical kit should provide equipment and reagents to make examinations for : taste, odour, colour, turbidity, hardness, pH, alkalinity, carbon dioxide, chlorides, iron, and manganese. Samples should also be taken for checking at a central laboratory in order to confirm field data. Chemical and physical examinations must be made during both dry and rainy periods, for the results may vary considerably.

Bacteriological examinations can also be made in the field with the new, portable, membrane filter incubator. Samples for such examinations should also be taken at different times of the year. Each time, a number of samples should be collected over a period of days, and no reliance should be put on the analysis of a single sample.

Another matter of importance in these investigations is a field evaluation of the sanitary and health hazards involved in the selection of a particular source of water. Bacteriological examinations of two different sources might give exactly the same result, but sanitary surveys aimed at determining the likelihood of their contamination by the environment might indicate that one source is dangerous and the other relatively safe. The greatest danger lies in contamination from human sources. In sparsely settled areas the chances of such contamination are remote as compared with those in congested areas.

It is impossible to lay too much stress on the importance of field studies for quantity and quality of available supply sources. The engineer responsible for these studies should make critical evaluations of the progress of his investigations. He should also exercise great care in carrying out field tests. It once happened that the use of a faulty reagent in making a field determination of the iron content of the ground water in an area caused rejection of this possible source of supply and consequently delayed the water programme for this area for several years, at great cost. A confirmation sample probably would have caught the error. In another instance, the omission of chemical tests in the investigation phase of a water-supply programme resulted in the destruction of the entire system, due to an excess of carbon dioxide in the water. In still other instances, slow sand filters have been built but could not be made to operate at times because of the excessive turbidity of the raw supply at certain periods. A thorough study of the characteristics of the watershed would have revealed the possibility of this phenomenon.

The responsibility of the investigating engineer cannot be over-emphasized; and he should discharge it with great care.

Design

Design guides

One of the most difficult and baffling problems facing the engineer in the planning of a small water-supply system for a rural community is the lack of criteria upon which an engineering design can be based. The engineer needs answers to such questions as : " What increase should be allowed for future population growth ? "; " Should provision be made for periods of peak demand ? "; and " What about storage ? ". Such technical questions have been thoroughly studied and standardized in textbooks dealing with design of water supplies for urban communities. However, for most rural, underdeveloped areas of the world, reliable design guides have not yet been established. Furthermore, certain elements of design are matters for local decision, depending on geography, local economy, custom, and other factors.

The experience gathered from several rural water-supply programmes has been analysed and is summarized below to serve only as a broad guide for engineers and health administrations concerned with such programmes. It is realized that there are wide variations in water-supply practice throughout the world and that every designer should not apply blindly the criteria listed here; instead, he should be able to make a critical analysis of the conditions and problems of the area under study and should develop applicable criteria. In so doing, he should contact the health administration of the area concerned with a view to consulting the minimum standards for design and construction which this administration may have issued through its public health engineering division (see " The role of the sanitary engineer ", page 24).

There is, however, general agreement on the following fundamental point : in the design of rural water-supply systems, primary consideration should be given to the protection of the quality of the natural water selected, since treatment should be considered only as the very last resort (see page 35). This requires the incorporation in the design of necessary sanitary safeguards, beginning with the proper location of intake structures and pipes. Except in unusual circumstances, other engineering and structural elements should be conceived around this need.

Population

Even after the population of a rural town or village has been determined, it is difficult to forecast its rate of growth. Much depends on future economic developments which may affect the town itself or the surrounding countryside. In a few instances these can be judged with reasonable accuracy, but in most rural areas it is impossible to do so. It is necessary in estimating population growth to take into consideration such factors as

the character and location of the town, the present status and possible expansion of agriculture on which it may depend, and the presence, or the possibility of establishment, of small industries in the surrounding area. It must be remembered, however, that most of these factors, especially industrial development, may produce sharp deviations from the estimated growth of rural populations. The installation of a water scheme may in itself be one of the biggest factors in the expansion of a town, particularly in the tropics.

An additional difficulty in population forecasting is that, in the great majority of cases, only vague information can be obtained as regards recent population and economic development in the area under study. Under such conditions no systematic estimate can be drawn up, and the engineer must exercise considerable judgement in predicting future population.

There is no agreement among designers as to what should be a suitable period of design for rural water-supplies. For urban conditions it is customary to design water systems to serve the population expected in 10 to 25 years. On the basis of available data for some rural areas of the world, a 50% increase in population would appear to be the minimum figure upon which any rural water-supply design should be based, irrespective of the period of design adopted. Designing for too small a population can have disastrous effects if the town develops much faster than anticipated. At the same time, over-designing the system requires an exaggerated capital investment on the part of the present population. Neither of these solutions is desirable, and a compromise is necessary.

In some countries the answer to this problem has been to design the water-supply system in such a way as to facilitate its expansion by the future population, which will thus have to pay for its own needs but which will not have to reconstruct the whole system. Well supplies, for example, are relatively easy to expand where new wells can be constructed. The capacities of storage and treatment plants can also be easily increased if originally designed with this purpose in view. The expansion of distribution systems, however, is likely to be expensive; but its cost can be kept to a minimum by judicious planning of the original layout, which can take the form of centrally located loops made of pipes somewhat larger than necessary for immediate needs and reinforced later for the increased demand.

Consumption

Wells or taps

Few reliable data are available regarding water consumption when the source of supply is a hand- or motor-pumped well or a public tap. There has, however, been great interest in the determination in various areas of the maximum number of persons which should be served by one well or

one tap centrally located. This figure is used to calculate the number of water-distribution points required and to select the most convenient locations for these points in a given community.

Criteria used in different parts of the world vary widely. Ruiz,[a] from Colombia, recommends a figure of between 20 and 50 persons per tap or well. W. E. Wood,[a] in Nigeria, uses a figure of 500 persons per well. Y. M. Liu,[a] from Taiwan, reports that, in his country, every effort is made to limit the distance for water-carrying to 100 m (330 ft). It would appear that a figure of between 20 and 50 persons per well or tap is on the low side, while the figure of 500 persons per well is somewhat high. It would seem reasonable to assume that in the majority of instances a well or a tap should be provided for a maximum population of 200 persons.

The US Joint Committee on Rural Sanitation [37] is quoted below with respect to water quantity requirements in rural areas of the USA. The figures given may be used as a guide in preparing estimates, although local adaptations may be necessary :

Domestic use (per person) :

Household having	*Typical consumption*	
	US gal. per day	*litres*
1 hand pump	10	38
1 pressure faucet at kitchen sink	15	57
Hot and cold running water—kitchen, laundry, and bath	50	190

Camps and schools (per person) :

	US gal. per day	*litres*
Work camp with hot and cold running water—kitchen, laundry, shower bath, and flush toilets	45	170
Camp with flush toilets	25	95
Camp without running water or flush toilets	5	19
Day schools	17	64

Livestock :

	US gal. per day	*litres*
Per horse, mule, or steer	12	45
Per dairy cow (drinking only)	15	57
Per dairy cow (drinking and dairy servicing)	35	132
Per hog	4	15
Per sheep	2	7.5
Per 100 chickens	4	15
Per 100 turkeys	7	26.5

Garden, fire extinction, and other uses :

	US gal. per hour	*litres*
Garden hose, 16-mm ($^5/_8$-in.)	200	760
Garden hose, 19-mm ($^3/_4$-in.), 6-mm ($^1/_4$-in.) nozzle	300	1135
Fire hose, 38-mm (1 $^1/_2$-in.), 13-mm ($^1/_2$-in.) nozzle	2400	9080
Continuous-flow drinking fountain	75	285

[a] Personal communications. Wood explains, however, that the figure 500 is not put forward as an ideal one, but as a compromise between what is desirable and what is practicable at present in Northern Nigeria. The figure shoud be regarded as a minimum rather than a criterion.

Water supply with distribution piping

Here the range of available figures is not as great as it is for wells and taps. Rojas[a] in Colombia reports 150 litres per person per day, as does Sanches [b] in Brazil. Wagner & Wannoni [c] report 75 litres per person per day from Venezuela in 1948, while W. E. Wood [d] (Northern Nigeria) reports 50 litres per person per day and Y. M. Liu [d] (Taiwan) reports 60-80 litres per person per day. In France in 1954, a general water-supply survey [29] revealed that the average consumption per person served was 126 litres per day in rural areas and 245 litres per day in urban districts.

One of the best studies of water consumption in small rural towns was reported by Rivas & Kollar [31] in 1956 from Venezuela. These engineers measured the consumption from public taps and through the distribution system in 13 small towns in Venezuela. While they found wide variations among towns, their conclusions, based on measured quantities, are as follows :

Water consumption :

    30% from private connexions
    70% from public taps

    10 litres per person per day from taps
    190 litres per person per day through house connexions
    65 litres per person per day combined consumption

Recommended design figures for rural water-supplies :

    120 litres per person per day for design of distribution systems
    15 litres per person per day for public taps
    250 litres per person per day for private connexions

Minimum heads in small water-distribution systems are estimated to vary from 3 m to 15 m (4.3 pounds per sq. in. (p.s.i.) to 21.5 p.s.i). However, a minimum of 10 m (15 p.s.i.) is recommended when no provision is made for fire protection. Where fire hydrants are installed, a minimum of 25 m (35 p.s.i.) is required.

In making basic assumptions, the designing engineer must use his own judgement, based on experience in the country and the details of the particular project. For example, in a gravity system conveying water from an abundant source, a small increase in pipe diameter will result in a small increase in construction cost but an appreciable augmentation of carrying capacity and of water supplied to a community. In this case the design

[a] Pachon-Rojas, L. (1953) *Water-supply systems for rural areas and small communities, with special reference to Colombian experience* (Unpublished working document WHO/Env.San./61)

[b] Sanches, W. R. (1956) *Construction of water supplies in small communities : methods of financing* (Unpublished working document WHO/Env.San./95)

[c] Wagner, E. G. and Wannoni, L. (1953) *Anticipated savings in Venezuela through the construction of safe water-supplies in the rural areas* (Unpublished working document WHO/Env.San./40)

[d] Personal communications

may well be based on a larger per-head consumption than would have been adopted otherwise. Where water must be pumped at high cost, it is more logical to base the design of the system on a much smaller consumption figure. A similar reasoning applies to the design of storage capacities, depending on whether storage is to be provided in a surface tank or in an elevated metal tank.

Water Quality

Bacteriological quality

There is a direct relationship between the character and degree of pollution of raw water, the type and effectiveness of water-treatment processes, and the character and quality of the treated water produced. Stream pollution-control agencies, in countries where these exist, normally take into consideration the limitations of water-treatment processes when they establish stream-water quality standards, so that the quality of treated water delivered to consumers can meet prevailing drinking-water standards. The selection of a source of supply may be restricted because of economic or technical limitations involved in the use of normal water-treatment processes for making the water from this source safe for human consumption.

The effectiveness of a water-treatment process can hardly be established in specific, quantitative values. For instance, the bacteriological quality of a filtered, chlorinated water is dependent upon the bacterial content of the raw water; its chlorine demand; the coagulating, settling, and filtering characteristics of the treatment plant; the degree of uniformity of the raw water; and, not least, the integrity and ability of the treatment plant operator. Furthermore, the public health significance of the degree of bacterial pollution of a raw water, and hence of any bacteria remaining in the treated water produced, depends upon the probable source of contamination of the raw water with coliform organisms, which serve as an indicator of pollution. These organisms may have originated largely from surface drainage, a situation likely to be most noticeable when manured fields are found within the watershed involved. On the other hand, sewage pollution may be the chief source of such organisms, in which case their public health significance is enhanced and may be related to the incidence of intestinal diseases among the population contributing the sewage. Then, the probable ratio between the numbers of pathogenic organisms and of coliform bacteria in the polluted water will be considerably increased. Such conditions are often encountered in rural as well as semi-urban areas where intestinal diseases constitute a serious public health problem, the treatment of the sewage is not practicable, and effective water-treatment is beyond the economic and technical resources available.

It would seem, therefore, that any bacteriological standards of quality adopted for drinking-water on a country-wide basis might, upon superficial

analysis, appear to be too rigid for large areas where, because of economic and social conditions, they are most difficult to apply and enforce. However, it must be reckoned that the adoption under these circumstances of more lenient standards, because they appear to be more realistic, would only confuse the issue by lowering the goal of safety and potability without providing a meaningful substitute, inasmuch as such a compromise cannot be expressed in quantitative terms. Instead, it is preferable to keep the public health objectives of the water supply constantly in mind, but to appraise local situations and review pertinent information in the light of qualified professional judgement. Obviously this will require the engineer in some areas to rule out the use of many surface waters which might appear to be suitable and convenient sources of potable water supply, and to throw considerable emphasis upon the use of ground waters whenever feasible.

The above statement should not be interpreted to mean that surface waters, because of bacteriological considerations, are unsuitable sources of supply for rural communities. This would be far from the truth. In fact, the use of surface waters often makes it possible to provide consumers with ample quantities of water in their own homes, thus fulfilling most of the major health objectives of the systems. In some instances this is achieved by passing surface water through a simple and economical treatment plant which, however, may not be adequate to guarantee compliance at all times with existing bacteriological standards of quality. In most rural situations such a system may be considered as a step in the right direction, and is to be preferred to the appalling conditions under which, in the total absence of any tolerable supply, the villagers are forced to carry, or even to purchase, small amounts of raw and polluted water. As time goes on, public pressure, technological advances, and the development through training of local skills, will gradually bring about the improvement of plant efficiency, operation and technical supervision to a point where the enforcement of existing standards of water quality may be envisaged.

It is necessary and desirable to establish some form of control over rural water-supplies. However, in most countries of the world, routine bacteriological control, which is obligatory in urban communities, would be unrealistic under rural situations, as indicated by the above discussion. In the latter, the attention of the local health administration should be concentrated primarily on those major elements of location and design of the supplies which will afford natural protection later against outside contamination, and on routine sanitary inspections by qualified sanitarians, to educate the rural population in the application and enforcement of rural sanitation regulations. Periodically tests for physical, chemical, and bacteriological quality should be made for the purpose of detecting major health hazards and of providing a baseline for comparison with the

results of future examinations. The information to be supplied when submitting samples for examination is listed in Annex 4, page 271.

On the subject of bacteriological quality the report of the WHO Study Group on International Standards for Drinking-Water [48] states the following:

" That water intended for human consumption must be free from chemical substances and micro-organisms in amounts which would provide a hazard to health is universally accepted. Supplies of drinking-water should not only be safe and free from dangers to health, but should also be as aesthestically attractive as possible. Absence of turbidity, colour and disagreeable or detectable tastes and odours is important in water-supplies intended for domestic use. The location, construction, operation and supervision of a water-supply—its sources, reservoirs treatment and distribution—must exclude all potential sources of pollution and contamination.

" Some countries in the world have established standards of quality which are applicable to their respective areas and have developed a certain degree of uniformity in methods of analysis and in the expression of the results of such analysis. Other countries, however, lack official or recognized standards of water quality and have no accredited procedures for the examination of water to assess its quality and safety. During regional and international conferences sponsored by the World Health Organization, the problems of standards of quality for a safe and acceptable water-supply, and of accredited or approved methods for the examination of water, have been fully discussed by groups of expert hygienists and engineers concerned with matters of water sanitation. Great improvement in water quality can be achieved throughout the world if various treatment processes are made easily comparable by the adoption of uniform methods for the examination of water and for the expression of results of such examinations. Further, outbreaks of water-borne disease could be avoided through stricter control by the responsible water-supply and health authorities of the quality of water distributed for drinking purposes. The World Health Organization has therefore conducted a study of these problems, in collaboration with Member States and with the assistance of a number of experts, in an effort to offer technical guidance to health and sanitation administrations wishing to revise their regulations on water-quality control . . .

" *Recommended standards of bacteriological quality*

" Some public drinking-water supplies are chlorinated or otherwise disinfected before being distributed; others are not. Effective chlorination yields a water which is virtually free from coliform organism, i.e., these organisms are absent in 100-ml portions; if communal supplies which are distributed without treatment or disinfection cannot be maintained to the bacteriological standard established for treated and disinfected water, steps should be taken to institute chlorination or disinfection, or other treatment, of these supplies.

" A standard demanding that coliform organisms be absent from each 100-ml sample of water entering the distribution system—whether the water be disinfected or naturally pure—and from at least 90% of the samples taken from the distribution system can be applied in many parts of the world. Although there is no doubt that this is a standard that should be aimed at everywhere, there are many areas in which the attainment of such a standard is not economically or technically practicable.

" In these circumstances there would appear to be economic and technical reasons for establishing different bacteriological standards for public water-supplies which are treated or disinfected and for those which are not treated. The following bacteriological standards are recommended for treated and untreated supplies for present use throughout

the world, with the hope that improvements in economic and technical resoucres will permit stricter standards to be adopted in the future.

" The standards described below are based on the assumption that frequent samples of water will be taken ... For each individual sample, coliform density is estimated in terms of the ' most probable number ' in 100 ml of water, or ' MPN ' index... The use of the MPN index is recommended as the basis of quantitative estimation of coliform density after full recognition of its limitations. However, the value of the index is sufficiently enhanced by the use of data from a series of samples to warrant its use in the recommended standards.

" *Treated water*

" In 90% of the samples examined throughout any year, coliform bacteria shall not be detected or the MPN index of coliform micro-organisms shall be less than 1.0. None of the samples shall have an MPN index of coliform bacteria in excess of 10.

" An MPN index of 8-10 should not occur in consecutive samples. With the examination of five 10-ml portions of a sample, this would preclude three of the five 10-ml portions (an MPN index of 9.2) being positive in consecutive samples.

" In any instance in which two consecutive samples show an MPN index of coliform bacteria in excess of 8, an additional sample or samples from the same sampling point should be examined without delay. This is the minimum action that should be taken. It may also be desirable to examine samples from several points in the distribution system and to supplement these with samples collected from sources, reservoirs, pumping stations and treatment points. In addition, the operation of all treatment processes should be investigated immediately.

" *Untreated water*

" In 90% of the samples examined throughout any year, the MPN index of coliform micro-organisms should be less than 10. None of the samples should show an MPN index greater than 20.

" An MPN index of 15 of more should not be permitted in consecutive samples. With the examination of five 10-ml portions of a sample, this would preclude four of the five 10-ml portions (an MPN index of 16) being positive in consecutive samples. If the MPN index is consistently 20 or greater, application of treatment to the water-supply should be considered.

" In any instance in which two consecutive samples show an MPN index of coliform organisms greater than 10, an additional sample or samples from the same sampling point should be examined immediately. It may also be desirable to examine samples from several points in the distribution system and to supplement these with samples collected from sources, reservoirs and pumping stations.

" When accurate and complete data concerning the sanitary conditions at the sources of an untreated water-supply, covering all possible points of pollution, are available and indicate that indices higher than the esablished maximum may bear little relation to potential health hazards, the local health and water-supply authorities should be responsible for ruling that such higher indices do not constitute need for treatment of the water. "

One of the great and sometimes even insurmountable difficulties of making any kind of bacteriological examination of water in remote areas is the lack of laboratory facilities. The new microfilter technique with portable laboratory equipment gives promise of a solution to this problem, however. The WHO study group made the following comment on the use of this method :

4

" Field tests : the microfilter technique [19, 24, 33]

" The microfilter technique—or, as it is frequently designated, the membrane-filter technique—is considered to have potential value for the quantitative detection of coliform bacteria. It presents a promising development as a field test, particularly for areas in which excessive time would be required to send water samples to a central laboratory. Further research on details of the test, including the culture media to be employed and the time of incubation, is needed before this technique can be recommended as a standard procedure. Without doubt, the present membrane-filter technique, when used in full recognition of its limitations, is a valuable tool in the control of water-supply quality. "

Chemical and physical quality

Water of good chemical and physical quality is necessary from the points of view of its acceptability by the people, the protection of the health of the consumer, and the conservation of the water system. Every technician experienced in rural water-supply work has encountered situations in which offending chemical substances have made a water source unacceptable to the public even though its bacteriological quality was excellent.

Water containing amounts of carbonates and bicarbonates of calcium and magnesium in excess of 100 mg per litre is " hard " and requires a great deal of soap for washing clothes. In addition, it forms curds in combination with soap and leaves deposits on clothes and incrustations both in vessels in which it is heated and in distribution pipes and meters, thus reducing their capacity and even obstructing them completely. This constitutes a serious drawback in many rural areas where laundering is an important and widespread undertaking. Other salts (such as sodium chloride) in large doses can make water unpalatable and unfit for consumption. The limiting dose, however, will vary from person to person or from one group to another. In certain areas of North Africa, for example, it is customary for the local population to drink water containing as much as 3000 p.p.m. of chlorides, as sodium chloride.[a] Such a concentration of salts would have a laxative effect on people not accustomed to it.

Iron is frequently a cause of serious trouble in rural water-supplies, especially those from wells. In addition to causing unpleasant taste, discoloration of fabrics, and incrustations in pipes, it promotes the growth of *Crenothrix*, reddish-coloured bacteria. Iron is usually found in solution in water as ferrous oxide.

Water containing nitrate in excess of 50 p.p.m. (as NO_3) can cause methemoglobinaemia (blood changes and cyanosis) when consumed by infants. A high nitrate content may be found in calcareous regions and

a Krul, W. F. J. M. (1953) *Water quality.* In : *Proceedings : Seminar for Waterworks Operators,* New Delhi (Document issued by WHO Regional Office for South-East Asia and Government of India, Ministry of Health)

in polluted underground water which has undergone self-purification. The original pollution may be the result of application of fertilizers to cultivated land or of leachings from cesspools or livestock yards. [7]

Fluoride in concentration greater than 1.5 p.p.m. will cause the teeth of children and, to a lesser degree, of adults also to become brown-stained and pitted. As the concentration decreases, however, mottling becomes progressively less severe so that, at a level of about 1.5 p.p.m., it is of a mild to very mild degree. [50] Recent experience has shown that, at a level of 1.0-1.5 p.p.m. the " mottled enamel " produced in children's teeth reduces dental caries. For this reason the application of fluorides to public water deficient in fluorine content is receiving increasing acceptance. However, it requires special equipment, experienced personnel, and accurate control of dosage and cannot at the present time be carried out in most rural areas of the world.

Turbidity and colour are of much concern to rural water-supplies. Depending upon the character of the watershed, turbidity may vary considerably from one season to another because of rainfall. A sudden increase in turbidity may do serious damage, or at least stop the operation, of small water-treatment plants if adequate precautions are not taken in advance in order to allow for rejection of the incoming supplies at such times. Water from slow-moving streams and small lakes is likely to be coloured, at least during certain seasons of the year. Both turbidity and colour will cause discoloration of clothes and may be responsible for rejection of the supply if removal by simple and economical processes cannot be achieved.

This brief exposé shows that it is necessary to determine carefully the chemical and physical characteristics of the sources of water supply under consideration at the time of field investigation. The following suggestions are made on pages 27-29 of *International Standards for Drinking-Water* :[48]

"... In view of the wide variations in the chemical composition of water in different parts of the world, rigid standards of chemical quality cannot be established. The limits ... designated 'permissible' apply to a water that would be generally acceptable by consumers; values greater than those listed as ' excessive ' would markedly impair the potability of the water.

" However, these limiting concentrations are indicative only and can be disregarded in specific instances.

	Permissible	*Excessive*
Total solids	500 mg/l	1500 mg/l
Colour	5 units *	50 units *
Turbidity	5 units **	25 units **
Taste	unobjectionable	—
Odour	unobjectionable	—
Iron (Fe)	0.3 mg/l	1.0 mg/l
Manganese (Mn)	0.1 mg/l	0.5 mg/l

* Platinum-cobalt scale
** Turbidity units

	Permissible	Excessive
Copper (Cu)	1.0 mg/l	1.5 mg/l
Zinc (Zn)	5.0 mg/l	15 mg/l
Calcium (Ca)	75 mg/l	200 mg/l
Magnesium (Mg) . . .	50 mg/l	150 mg/l
Sulfate (SO$_4$)	200 mg/l	400 mg/l
Chloride (Cl)	200 mg/l	600 mg/l
pH range	7.0-8.5	Less than 6.5 or greater than 9.2
Magnesium + sodium sulfate	500 mg/l	1000 mg/l
Phenolic substances (as phenol)	0.001 mg/l	0.002 mg/l

" There are certain substances which, if present in supplies of drinking-water at concentrations above certain levels, may give rise to actual danger to health. A list of such substances and of the levels of concentration which should not be exceeded in communal drinking-water supplies is given below :

Substance	Maximum allowable concentration
Lead (as Pb)	0.1 mg/l
Selenium (as Se)	0.05 mg/l
Arsenic (as As)	0.2 mg/l
Chromium (as Cr hexavalent)	0.05 mg/l
Cyanide (as CN)	0.01 mg/l

" The presence of any of these substances in excess of the concentrations quoted should constitute grounds for the rejection of the water as a public supply for domestic use. "

Several types of portable laboratory field kits have been designed to facilitate the physical and chemical examination of water on the spot.

Fig. 3.   A PORTABLE WATER-LABORATORY FIELD KIT
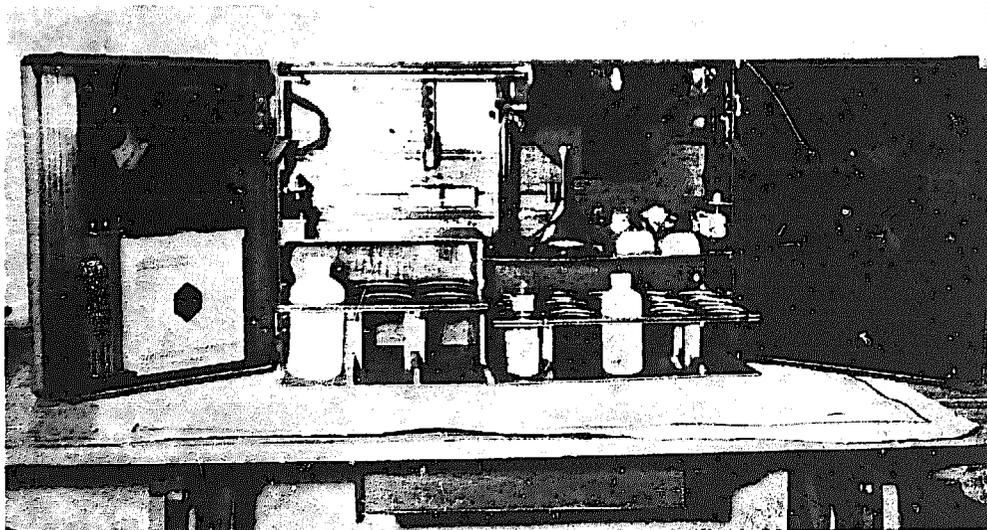
A typical kit, illustrated by Fig. 3, usually includes the following equipment :

Tests	Reagents and equipment
General	1 Taylor water analyzer
	9 tubes
	1 0.18-ml pipette
	1 27.0-ml pipette
	1 25-ml burette
	1 evaporating dish
	1 box filter paper
	1 Erlenmeyer flask — 250-ml
	1 250-ml beaker
	1 100-ml cylinder
	1 50-ml volumetric flask
	1 100-ml volumetric flask
	1 alcohol burner
	1 × 500 ml alcohol
	2 × 500 ml distilled water
	1 towel
Colour	1 slide
Chlorine	1 × 300 ml orthotolidine
	1 × 300 ml 0.5% sodium arsenite
	1 slide
Total iron	1 slide
	1 × 300 ml 1 : 1 (6N) HCl
	1 × 300 ml thiocyanate
	1 × 300 ml permanganate
Manganese	1 slide
	1 × 300 ml 1 : 1 nitric acid
	1 × 300 ml silver nitrate
	1 × 100 g ammonium persulfate crystals
Fluoride	1 slide
	1 × 300 ml acid indicator
pH	4 slides
	4 × 300 ml indicators
Alkalinity	1 × 500 ml N/50 HCl
	1 dropper bottle of methyl orange
	1 dropper bottle of phenolphthalein
Hardness	1 × 500 ml soap solution
Chlorides	1 × 100 ml silver nitrate
	1 × 100 ml potassium chromate

Carbon dioxide and corrosiveness : Curves are furnished to obtain carbon dioxide content and corrosiveness from pH and alkalinity.

Corrosion and scale

Hydrogen sulfide, dissolved oxygen, and carbon dioxide in water cause acidity and are responsible for corrosion of iron pipes.   Hydrogen sulfide, which is sometimes found in deep-well water, is a product of decomposition of organic matter.   It attacks cement and concrete and destroys storage tanks built of these materials.   Dissolved oxygen combines with ferrous iron, which is sometimes found in solution in well water, and produces ferric hydroxide, which is insoluble and gives the water a rusty colour. It may also cause serious corrosion of distribution pipes and house plumbing pipes.

Perhaps the most important and troublesome of the three products mentioned here is carbon dioxide, which is often found in well water and in surface water drawn from heavily wooded watersheds or from the lower layers of deep ponds.   Carbon dioxide in water is responsible for heavy and rapid corrosion of unprotected pipes, thus creating increasing difficulties with maintenance and operation of a water system.   Various materials, mostly bituminous compounds and cement, are used by manufacturers for lining the interior surfaces of pipes against corrosion.   These materials are also used to protect outside pipe surfaces against corrosion caused by the contact of pipes with certain soils and, under certain circumstances, by electrolysis.

Natural water containing carbon dioxide will dissolve carbonates from rocks in the ground, thus producing soluble bicarbonates.   Depending upon the relationships between the bicarbonate alkalinity and the pH of the water on the one hand, and between the free carbon dioxide and the alkalinity on the other, the water will either be corrosive or, on the contrary, will deposit a film of carbonate on the inner surface of pipes.   This film may sometimes develop sufficiently to become a thick scale which obstructs small distribution and service pipes, water meters, etc.   The prevention of corrosion and scale rests upon the chemical control and maintenance of the proper equilibrium between the three factors mentioned, i.e., by reducing the content of carbon dioxide or increasing the alkalinity as determined by special tests.   Except in rare instances, this type of chemical control is beyond the technical resources of small rural water-supply systems and, therefore, will not be discussed here in greater detail. However, treatment procedures applicable to such systems are given later under " Corrosion control ", page 180.

INSTALLATION OF VARIOUS TYPES
OF WATER-SUPPLY SYSTEMS

Chapter 3

GROUND WATER

Engineering and Geological Considerations

Ground water serves the great majority of people who live in rural areas and have a water-supply system of one type or another. The reason is that, among the various sources of supply, ground water is by far the most practical and safe in nature. Even in a highly industrialized country such as the USA, municipal ground-water installations far outnumber surface-water supplies. It is very probable that, for a long time to come, ground water will be the most important source of supply for most rural communities of the world.

The advantages of ground water are:

(1) it is likely to be free of pathogenic bacteria;

(2) generally, it may be used without further treatment;

(3) in many instances it can be found in the close vicinity of rural communities;

(4) it is often most practical and economical to obtain and distribute;

(5) the water-bearing stratum from which it is drawn usually provides a natural storage at the point of intake.

The disadvantages are:

(1) ground water is often high in mineral content;

(2) it usually requires pumping.

In ground-water-supply investigations and design, the engineer is concerned with the following steps:

(1) to find it in the required quantity and quality as near as possible to the centre of consumption, in order to reduce transport costs;

(2) to extract it by means of a system which produces the quantity required, safeguards the quality, and, at the same time, involves the least capital outlay;

(3) to transport the water to the consumer in a way which requires the least amount of operational and maintenance skill and cost.

This section is concerned chiefly with the first step mentioned above. Obviously, a rural town or village cannot afford the cost involved in bringing water long distances by gravity or, much less, by pumping. The

water which will serve a rural community must therefore be found within a rather limited area.

A brief discussion regarding the occurrence of ground water and the characteristics of underground formations from which it can be extracted may be valuable to the designing engineer.

Fig. 4. GEOLOGICAL FORMATIONS
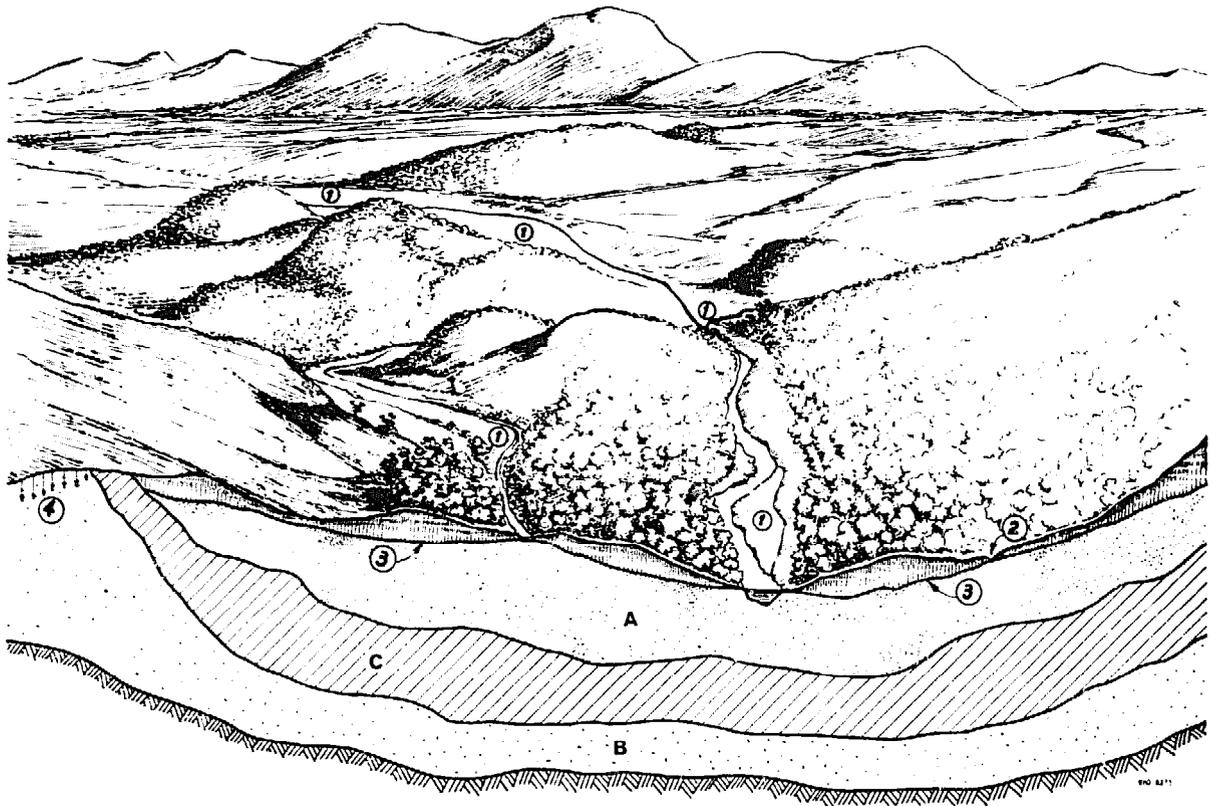
1 = Areas where there are good possibilities of obtaining water from infiltration galleries, well-point systems

2 = Ground water is outcropping at this point, so that a flowing spring is formed. At the foot of river banks and hills other springs may possibly be found.

3 = Top of ground-water table

4 = Area of infiltration to supply formation B

A = Non-confined (non-artesian), water-bearing formation covered with top · ɔil

B = Confined (artesian), water-bearing formation

C = Impervious rock, or hard-pan formation

To supply a village situated along the banks of the main river in this rolling country with a good ground water table, the first thing to look for is a spring above the town that could be developed and would flow by gravity. If no springs were found within a reasonable distance above the point of consumption, some might be found outcropping near the stream bed. If no springs were found within a reasonable distance, any well penetrating formation A would produce water. If large quantities were required, a well-point system or a gallery at points indicated would probably work. A deep well, properly constructed and developed, penetrating formation B would probably produce considerable water.

The engineer making a survey of this area, knowing what is shown in this figure, ought to follow a procedure such as described above.

Fig. 5. OCCURRENCE AND DISTRIBUTION OF SUB-SURFACE WATER

The chart classifies sub-surface water as follows:

ZONE OF INTERCONNECTED OPENINGS

UNDERSATURATED ZONE (ZONE OF AERATION) — SUSPENDED WATER — VARIETIES OCCURRING THROUGHOUT ZONE OF SUSPENDED WATER

SOIL WATER — Limited to the soil and reached by roots

PELLICULAR WATER — Adheres to rock surfaces throughout zone of aeration and is not moved by gravity but may be abstracted by evaporation and transpiration

GRAVITY OR VADOSE WATER — Moves downward by force of gravity throughout zone

PERCHED WATER — Occurs locally in the zone above an impervious barrier

CAPILLARY WATER — Occurs only in the capillary fringe at the bottom of the zone

SATURATED ZONE — GROUND WATER (PHREATIC WATER)

FREE WATER — Occurs below the water table and is bounded by the first effective confining stratum

CONFINED WATER — Occurs beneath a confining stratum

FIXED GROUND WATER — Occurs in subcapillary openings, not moved by gravity

CONNATE WATER — Water entrapped in the rocks at the time of their formation

ZONE OF DISCONNECTED OPENINGS

INTERNAL WATER
a. Chemically combined water
b. Water fixed in disconnected interstices
c. Water dissolved in magmas

Illustration labels: SOIL A/B/C · EXCESS OVER PELLICULAR WATER MOVING BETWEEN FILMS BY GRAVITY · PERCHED WATER TABLE · (ENLARGED) CAPILLARY FRINGE · WATER TABLE · FREE WATER · CONFINING STRATUM · CONFINED WATER · CONFINING STRATUM

Fig. 6. COMPARISON OF FREE AND CONFINED GROUND WATER
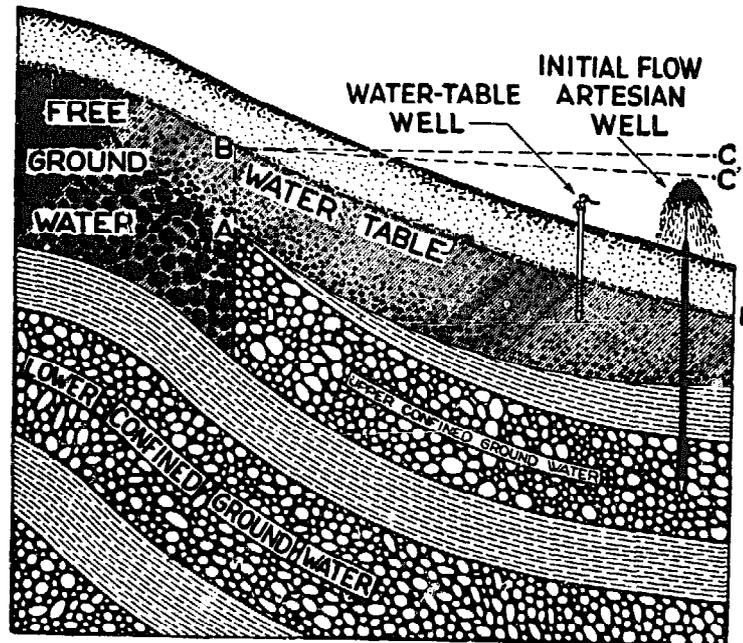
BC = theoretical static level of confined water body
BC' = pressure gradient; indicates actual static level in wells piercing the conduit

Occurrence

Ground water is that portion of the atmospheric precipitation, mostly rainfall, which has percolated into the earth to form underground deposits called aquifers (water-bearing formations) (see Fig. 4). These can be tapped by various means, to be discussed later; and, in the great majority of cases, they can be used without further treatment for individual and community water-supplies in rural areas. Fig. 5 shows the occurrence and distribution of subsurface water.

The great majority of wells for rural water-supplies take water from the zone which Tolman [35] defines as the " free-water zone " (Fig. 5, 6). These will usually be jetted, dug, driven, or bored wells. Infiltration galleries also take water from this zone. Drilled wells often penetrate the confined water aquifer. It is from this stratum that flowing wells are developed.

The aquifer must be supplied with an ample quantity of water if it is to serve as a source. It is simply a reservoir and can be depleted in the same manner as a surface reservoir if its supply is inferior to the demand placed on it. In rural areas this is very seldom a concern as the aquifer will usually be replenished sufficiently to supply the relatively small demands of rural communities. An element of greater significance for the engineer

searching for ground water pertains to the characteristics of the soil for-
mation of the aquifer, i.e., to the ability of the aquifer to give up water
and, therefore, to serve as a reliable source of supply.

The quantity of water that can be extracted from an aquifer will depend
on (1) its porosity and permeability, and (2) the draw-down in the well.
The porosity and the permeability of a formation are limited by nature;
and, while gravel packing [a] may alter conditions somewhat in the imme-
diate vicinity of a well intake, the general nature of the aquifer is fixed and

Fig. 7.   SHALLOW WELL IN FREE-WATER ZONE
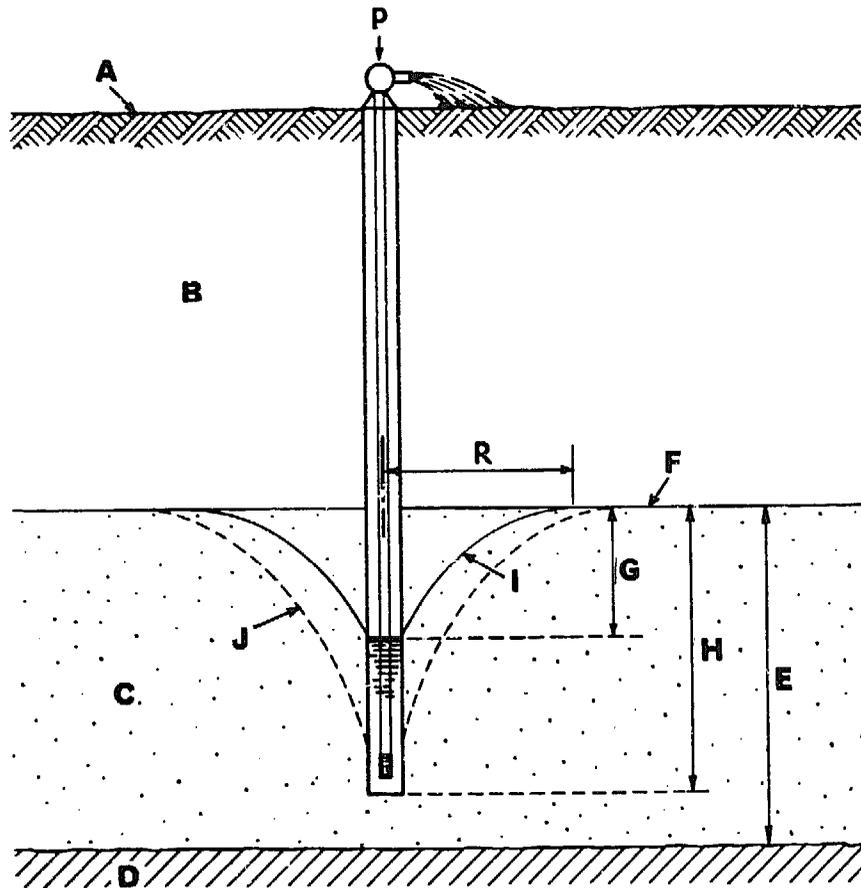
WHO 8246 b

A = Ground surface
B = Top layers of soil
C = Water-bearing stratum
D = Impervious stratum
E = Thickness of water-bearing
     stratum
F = Water table

G = Draw-down
H = Depth of penetration of well
     into aquifer
I = Draw-down cone
J = Curve of maximum draw-down
P = Pump
R = Radius of circle of influence

[a] Gravel packing is the development of a pocket of coarse, graded sand and gravel around a well intake-
pipe to exclude fine sand and improve entrance velocity of water into the pipe.

cannot be modified. The draw-down in a well, however, can be varied within the limits of the thickness of the aquifer, the penetration of the well into the aquifer, and the capacity of the pump used (see Fig. 7, 8).

Fig. 8. WELL TAPPING CONFINED WATER
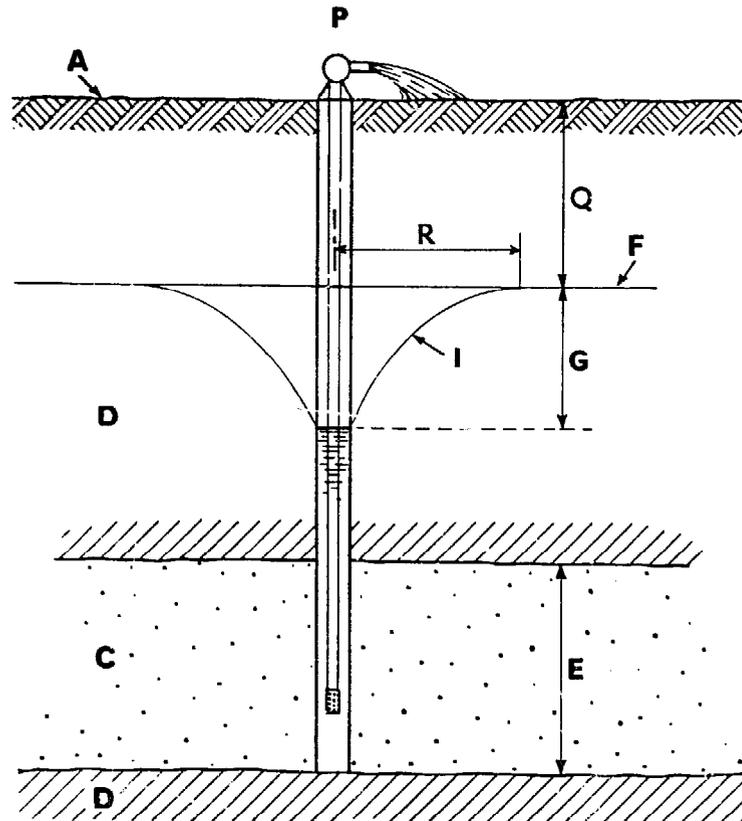
A = Ground surface		**G**	Draw-down
C = Water-bearing stratum		**I**	Draw-down cone
D = Impervious stratum		**P**	Pump
E = Thickness of water-bearing stratum		**Q**	Depth to water table
F = Water table		**R**	Radius of circle of influence

The porosity of a formation is the pore space between the particles which make up the formation. It is the volume of the voids. Obviously, solid piece of dense rock will have low porosity—a low volume of pore space or voids. If many pieces of stone of varying shapes and sizes replace the single piece of the same total volume, the porosity will increase since the voids are increased. Steel [32] gives the following figures regarding the porosity of common soils and rocks : sands and gravels of fairly uniform size and moderately compacted, 35%-40%; well-graded and compacted sands and gravels, 25%-30%; sandstone, 4%-30%; chalk, 14%-45%; granite, schist,

and gneiss, 0.02%-2%; slate and shale, 0.5%-8%; limestone, 0.5%-17%; clay, 44%-47%; topsoils, 37%-65%. Fair & Geyer[16] report that silts may be as high as 80% in porosity. It can be seen that soils with fine, separate particles, such as clay, topsoil, and silt, have a very high porosity. In other words, they have a big volume in which water can be stored.

Ground formations, however, have a certain tendency to hold the water and to give up only a part of it. This characteristic of a soil formation is called permeability; it is the quality of a formation which controls the passage of water through it. From a knowledge of hydraulics, it is obvious that water will pass through large openings more easily than it does through small ones.

Clays and topsoils have high porosity (large volume of voids) but low permeability (very small opening between particles), so that water passes through them with great difficulty. Gravels and sands, on the other hand, are permeable and therefore allow ground water to pass with relative ease. This type of formation is also porous, as can be seen above, so that it can store large quantities of water. These, then, are the water-bearing formations most amenable to the development of wells and most important to the engineer in searching for a rural community water-supply. Sandstone is both porous and pervious and therefore an excellent aquifer which can be tapped to produce large quantities of water, especially if it is confined as shown in Fig. 4 (formation B) and Fig. 5 (see pages 58 and 59). Where it is known, for example, that sandstone underlies an area, and where no other readily available source is found, a test hole into this stratum would be a good risk. Chalk formations in the British Isles and in Haiti are known to produce reasonable quantities of water.

Except for unusual geological features or underground dams, it can be said that, in any drainage basin, ground water always flows towards the principal streams (Fig. 4). While there are exceptions to this rule, the best place to look for shallow ground-water is at the bottom of draws and valleys. It is in this area that pockets of sand and gravel may have been deposited. If these are close to the present stream or in an old course, they will probably be well supplied. Underground sampling by boring or jetting in these areas will usually be profitable. In this way, samples of the underground formation can be taken and examined to determine the characteristics of the aquifer and its ability to supply the quantity of water needed. Fortunately, a great many small towns in rural, underdeveloped areas have been built along natural watercourses, so that the possibility of finding available ground water as a source of supply may be somewhat improved in such areas.

Finding ground water

Rarely will the investigating engineer have at his disposal the results of previous geological studies of the particular area involved and, even more

rarely, the services of a specialist in the field of ground-water geology. If such studies or services are available, they should be used by all means. If not, the engineer will usually have to exercise his own knowledge and judgement and to utilize his own resources. If he decides that it will be necessary to search for ground water, he may wish to consult helpful sources of information on this subject. [6, 13, 35]

In prospecting for ground water, the first step is to review reports (if any) of relevant geological studies which indicate the nature and perhaps the characteristics of the underlying formations. Depending on the purpose for which these studies were made, they can be very useful in orientating the initial stage of investigation. Secondly, the examination of existing wells—their profiles, production, water quality, and location—will also give valuable information. Thirdly, the sinking of test holes will be most profitable. While the last will entail more work and expense than the previous steps, experience has shown that test holes are, in almost every case, indispensable and, in the long run, economical as well. Samples and profiles of the ground formations can be obtained from test holes, thus giving information as to the nature of the aquifer, depth of the water table, and quality of the ground water. Furthermore, many test holes can also be pumped in order to obtain an indication of the possible yield of the aquifer. Most experienced technicians in the field of ground water will vigorously argue the need for exploratory borings and will insist that they are indispensable in pr viously unexplored areas. A fourth means of obtaining information about ground water is through the use of an electric-resistance system. Bymeasurement of the resistance of the earth at the desirable well locations and application of formulae developed by the manufacturers of the equipment, reasonably accurate ground data can be obtained. The interpretation of the results of such tests, however, requires considerable experience; and this method is most useful to supplement and extend the information obtained from actual well profiles. When properly employed, this method can be very valuable. The equipment is reasonable in cost and relatively simple to operate.

Test holes

One of the most important techniques available to the water-prospecting engineer, and one which he must master if he is to be successful, is making test holes. The type of information which can be obtained through this technique has already been listed in the previous paragraph. There is, unfortunately, no simple, inexpensive method of obtaining all the required data from one hole. It is necessary, therefore, to adopt a method which is compatible with the objective of the project concerned.

There are several methods for making test borings. They vary from simple to complex operations, and the necessary equipment also varies

accordingly.   The method adopted will depend on the purpose of the hole and the magnitude of the project.   If, for example, the objective were to construct a dug well of small capacity to supply a few hundred people, there would be no justification for large expenditures on prospecting. On the other hand, if ground water were being sought to eliminate expensive treatment works or to supply a large number of communities in an area-wide programme, a considerable expenditure would be justified for putting down several test holes.   With a reasonable amount of equipment (small hydraulic drill, pump, casing, screens, and tools), an experienced crew can put down many holes and obtain a great deal of information in a matter of days.

The cased hole is recommended for those who are beginning to prospect for water.   The small-diameter casing, 4-10 cm (2-4 in.) in diameter, is not too expensive for water programmes of reasonable size; and the necessary equipment and supplies are not too cumbersome to transport.   Earth material from inside the casing can be bailed out with sand bailers (see Fig. 9) or washed out in the manner shown in Fig. 10.   In any case, samples should be taken with a bailer and a large enough quantity assembled to obtain a representative sample.   For this, several bailers full of material should be put together in a box, mixed, and a sample taken from the batch.

Fig. 9.   TYPES OF BAILERS AND BUCKETS USED FOR REMOVAL OF MATERIAL
FROM HOLES
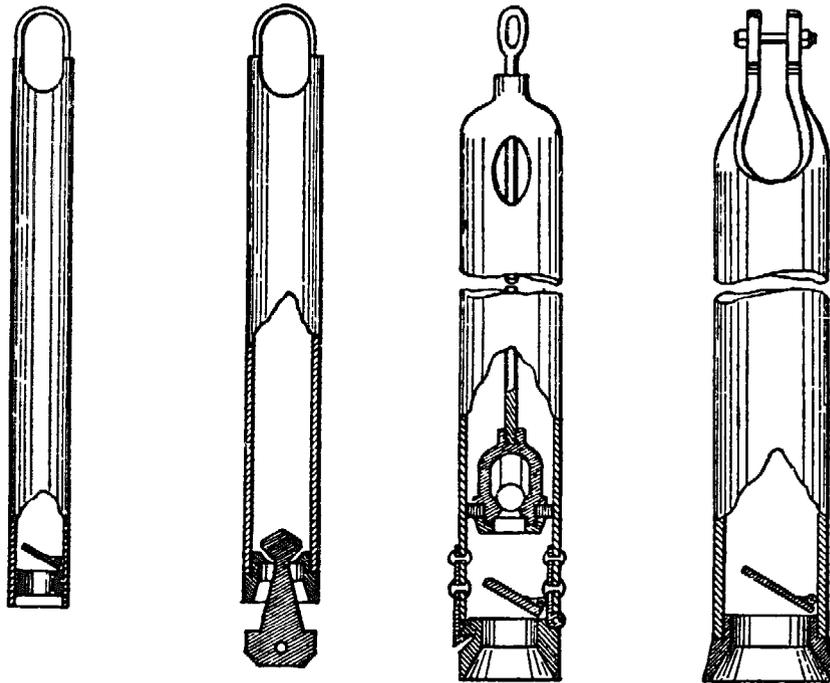
When the casing is being washed or jetted down, the problem will be to
decide when and how to take samples. The reason for this is that the
water jet causes the separation of the fine- and coarse-ground materials,
and it takes a great deal of experience to tell much about the strata from
which these materials came.

Fig. 10.   HYDRAULIC METHODS OF EXPLORATION

Jetting Method   Hydraulic Method   Hollow Rod Method
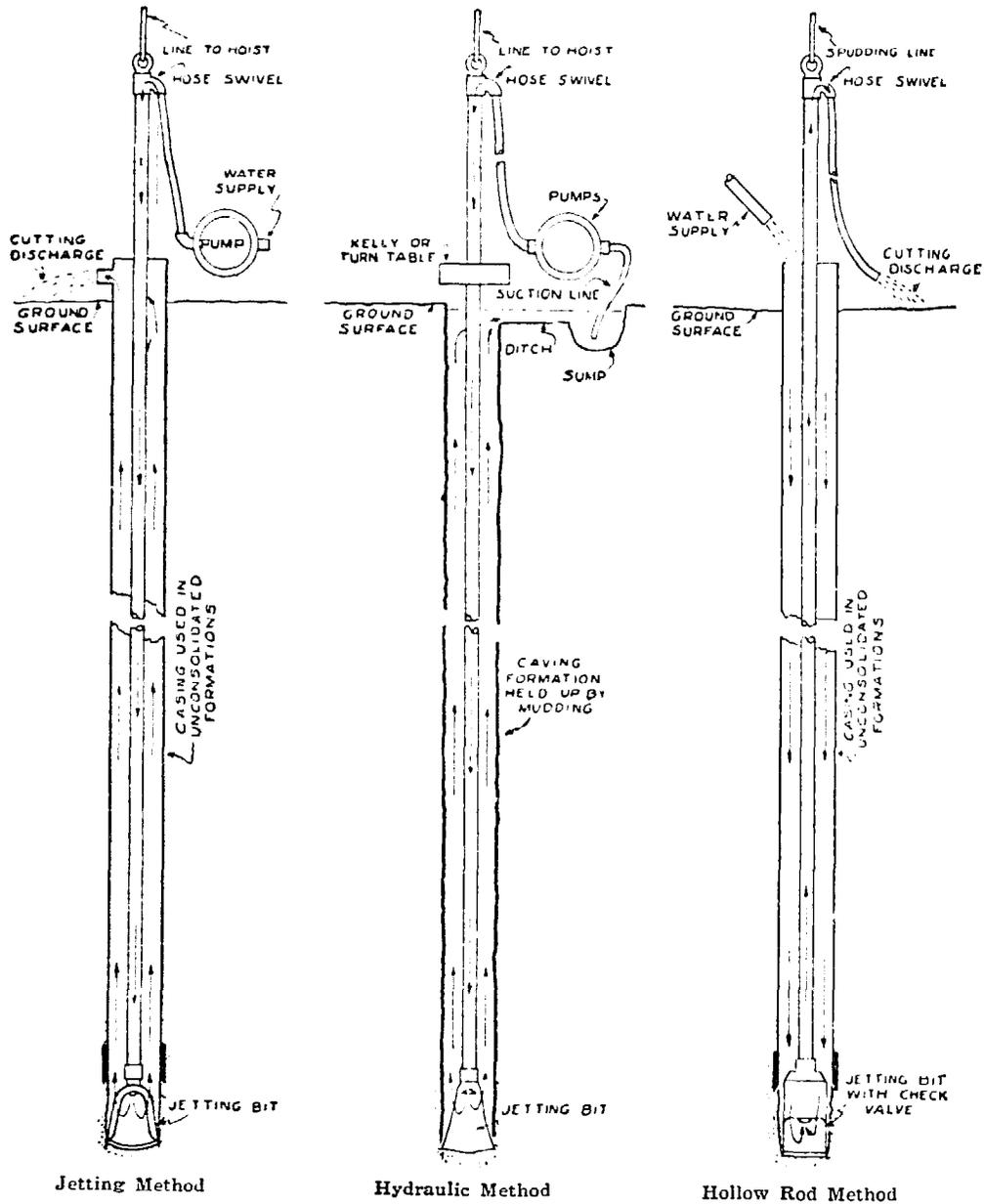
Reproduced from Bennison, E. W. (1947) *Ground water: its development, uses and conservation*, p. 99, by
kind permission of Edward E. Johnson, Inc., St Paul, Minn., USA

For small wells, therefore, samples should be taken every 2 m (6½ ft) or so; but, once the water table is reached, samples should be taken more often. The water-jetting bit can be raised and samples taken with a bailer or, preferably, with an auger. It should be kept in mind that most well-prospecting holes for rural water-supplies will be less than 100 m (330 ft) in depth and that the average test hole will probably be around 50 m (165 ft) deep. Therefore, the additional manipulation of tools involved in taking ground samples (i.e., the changing, raising, and lowering of tools) in most instances will not constitute a major loss of time in the construction of test holes.

Information can be obtained from uncased holes dug by small rotary drilling machines or by straight jetting of small-diameter pipes. The Serviço Especial de Saúde Pública of Brazil has used jetting methods extensively throughout the country and has put down thousands of holes in recent years. One of their best construction foremen has always preferred to jet with a 2-in. (55-mm) screen on the end of the jetting pipe. Then, when the water-bearing formation is penetrated, jetting operations are stopped, the screen is washed, and the well-hole is developed and tested for yield with a suitable pump. Where small quantities of water are required, this has proved to be a simple and highly economical procedure. More than half of the time this foreman has been able to obtain a quantity of water large enough to satisfy the objective of the project. Following the tests, the screen and test equipment are removed, and a permanent well-installation is jetted down or specifications are given for construction at a later date. Application of this procedure, of course, requires much experience and a thorough knowledge of the geology of the area under investigation. There are many similar places in the world, however, where the same technique can be used with profit.

As samples are collected, careful notes should be kept regarding the depths at which they were taken and the number of feet or metres of the ground layers which they represent. The character of the formations, the presence of stones, boulders, etc., and the degree of difficulty of boring through them should also be noted.

Frequently the question is in doubt as to whether one should try for a permanent well out of the test-hole operation. The authors believe that, where conditions are fairly well known and the well-drilling crew is experienced, it is certainly worth while to do so, as it is an economical procedure. In one area in Brazil, within a period of 16 hours a 30-cm (12-in.) casing and screen were jetted 24 m (79 ft) into a water-bearing stratum, and produced 2000 litres of water per minute when tested. The equipment required consisted of two construction pumps of a capacity of 113 550 litres (30 000 US gal.) per hour each. In this particular case, everything was known about the ground strata from previous well constructions in the area, and it would have been of no avail to prospect further. As it turned out, this was a

very economical operation. A highly productive well was sunk and testing started the same day. The knowledge required to make this feat possible, however, had been accumulated over many years.

Wells

There are three principal methods of well construction. Each method has its own advantages given certain conditions, and all three types and combinations of them are widely used under different circumstances.

The type of well most widely used throughout the world is the hand-dug well. Employing traditional methods, often identical with those used hundreds of years ago, aborigines in all parts of the world rely on open, hand-dug wells for their principal source of water. There are many Biblical references to well-digging, and there are wells in existence today which are believed to have been sunk in ancient times.

The use of modern materials, tools, and equipment has transformed the hand-dug well from a crude hole in the ground, uncertain in results, dangerous to its constructors and users, and the focus of parasitic and bacterial diseases, to a safe structure based on sound engineering principles, and a hygienic and reliable source of water. The hand-dug well is still one of the cheapest methods for providing a small supply of water for villages, but it is relatively expensive for the individual family. Although its construction is a rather slow process, it has many advantages which generally outweigh speed. The equipment used is simple and light, enabling sites remote from a road to be served; the process is easily taught to unskilled workers, thus cutting supervision to a minimum; and, with the exception of cement and reinforcing steel rods (items relatively easy to transport), the materials used are usually obtainable locally. A further advantage in newly developing countries is that it adapts and improves on traditional methods of construction, which tends to increase the skill in other directions of those people trained in well-sinking. When completed, the well provides not only a source of water, but also a reservoir enabling water which percolates into it at night to be drawn off during the day. Where demands are low, this property is of particular value, since weak aquifers with a low rate of flow into the well can be utilized.

Hand-dug wells naturally have certain limitations. While successful wells have been sunk in special circumstances to depths of over 120 m (400 ft), half that distance is usually considered the limit of practical sinking. For the installation of mechanical pumps designed to extract large quantities of water over long periods, the diameter of a dug well often has to be so large as to be uneconomical as compared with a bore-hole. Hard rock can be penetrated to a depth of a few feet (one metre or so) by the use of explosives; but it is extremely slow work; and, for considerable thicknesses of rock, bore-holes are usually preferable.

In rural areas, however, where a supply of a few hundred gallons per hour (such as can be drawn by buckets, hand, animal, or windmill pumps) is required from unconsolidated formations, the hand-dug well has so many advantages as to make it an almost invariable choice.

The drilled well, usually referred to as a bore-hole, has many advantages in other circumstances. Much greater quantities normally can be extracted

Fig. 11. DRILLING AND BORING METHODS OF EXPLORATION

Sand Bucket Method   Auger Bucket Method   Core Drill Method
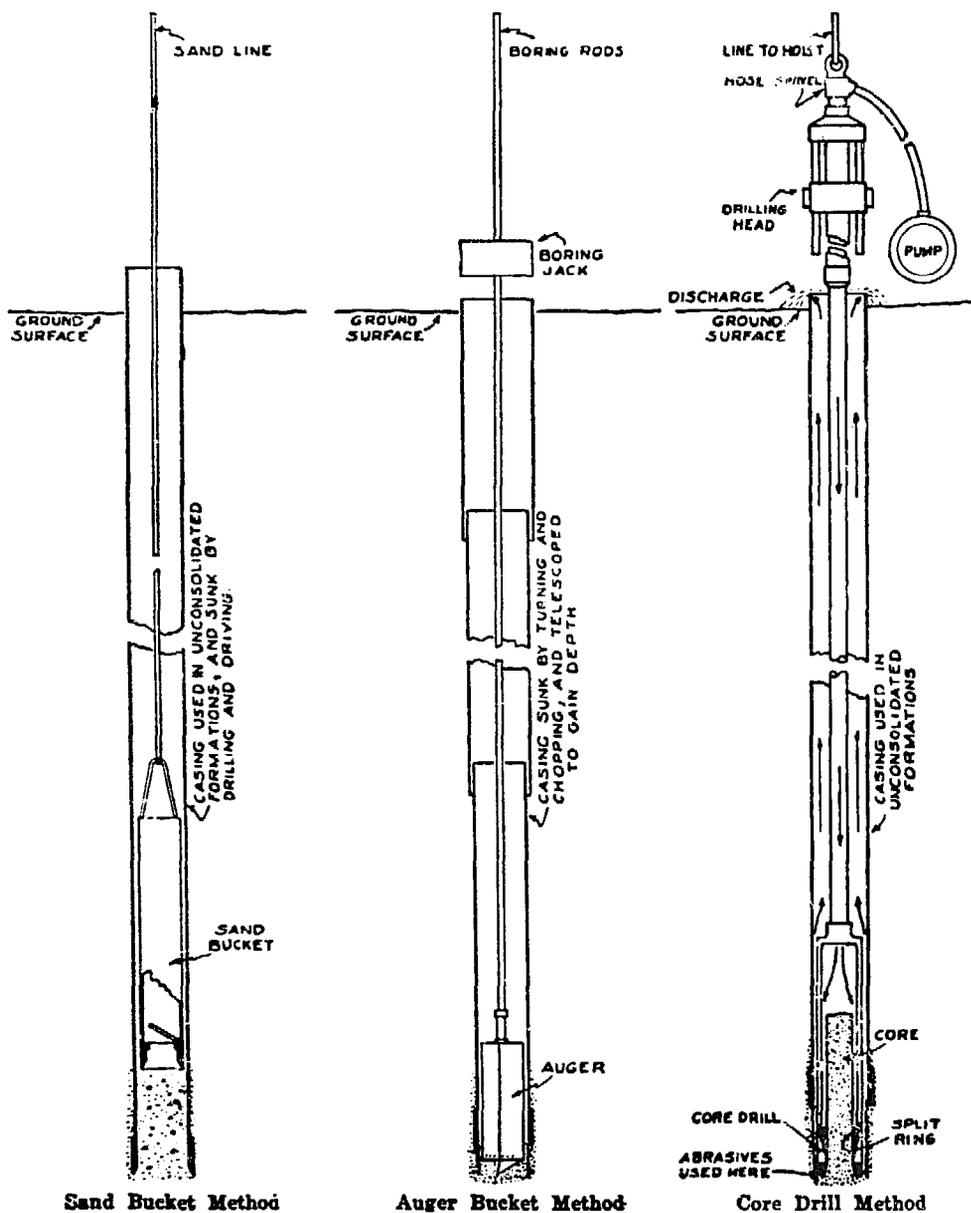
Reproduced from Bennison, E. W. (1947) *Ground water: its development, uses and conservation*, p. 104, by kind permission of Edward E. Johnson, Inc., St. Paul, Minn., USA

from a single hole, often making it the only practical method of supplying urban communities or other demands involving heavy pumping. Given good access roads over which the rig and casing can be moved easily to the site, the actual construction of the hole is usually a quicker operation than that of the hand-dug well although, when sites are widely scattered, the time consumed in moving the heavy equipment must be added to the construction time for a true comparison. Hard rocks can be penetrated to a considerable depth, although drilling in these hard formations naturally greatly slows operations. The most important advantage is the depth and rapidity with which a bore-hole can be drilled, the practical limit being governed solely by the size of the rig used (see Fig. 11).

For depths of more than, say 60 m (200 ft), therefore, particularly where large quantities of water are required, the bore-hole is the method usually selected. Under certain conditions it is possible to combine hand-dug and drilled wells to great advantage. Particularly is this so when a relatively small quantity of water is required for a village or hamlet and the only supply is a pressure aquifer lying too deep for hand-sinking methods. This condition is quite a common one in the tropics, and communities are usually small in areas where water is available only at a considerable depth. Costly bore-holes, of sufficient diameter to take pumps, are generally an uneconomical proposition in these cases. But, if a hand-dug well is sunk and a small-diameter—i.e., 8-cm or 10-cm (3-in. or 4-in.)—bore-hole is inserted through the bottom of the well to a sub-artesian aquifer, then water will rise into the well throughout the whole 24 hours; and the well itself will act as a reservoir from which water can be drawn during peak periods.

The third method in general use is the tube well—a perforated or screened pipe which is jetted (*jetted well*) or driven (*driven well*) into a shallow aquifer. This may be a small-diameter casing fitted with a hand pump, or a large-diameter casing fitted with a mechanical pump. Properly constructed and under suitable circumstances, these tube wells can give surprisingly large quantities of water; but they are limited in the depths to which they can be inserted, and the ground formation must be appropriate for their use. Their most common application in the tropics is for the extraction of water from water-bearing sands, especially those underlying the beds of ephemeral streams, and for making use of the natural filtering properties of sandy beds of perennial rivers by taking water from below the beds instead of from the rivers themselves.

In the following paragraphs, typical methods of well construction are described. It is obvious that no single method of construction is applicable in all countries, regardless of geological and other field conditions. There are many other construction procedures in application in the world today, and it would be materially impossible to describe them all. Experience shows that it is often necessary for the field engineer to amend standardized

procedures in the light of geological findings and to improvise tools and procedures which will help in speeding up the work.

Dug wells

When a big well-construction programme is to be carried out within a large rural area or country, it is of great importance that methods and equipment should be standardized as far as possible so that the initial training of the crews will enable them to build similar wells in different areas and under different circumstances without constant supervision. Certain features of the work must be adapted to different conditions—e.g., the thickness and reinforcement of the linings must vary according to the type of ground encountered, and the well intake (that part of the well through which the water enters) must suit the local conditions—but, in general, the basic methods, materials, and dimensions should remain as constant as possible.

In the past, wells have been constructed of circular and of square sections; but the advantages of economy and strength are so overwhelmingly with the former that virtually all wells constructed now are circular in plan.

Diameter

The first consideration, then, in designing a well is its diameter; neglecting for the moment large-diameter wells built for special purposes, the size of a completed well represents a compromise between economic and practical considerations. It has been found that the cost of a lined well varies almost exactly with its diameter, taking into account the increased thickness of lining necessary in a larger well. The minimum diameter is limited by the room available for a man or men to work; experiments show that a diameter of about 1 m ($3^1/_4$ ft) is necessary for one man and about 1.3 m ($4^1/_4$ ft) for two men. It has been found that the efficiency of two sinkers working together is more than twice that of a single man, and consequently a 1.3-m ($4^1/_4$-ft) diameter is a convenient standard size. Other considerations affecting this decision are the greater natural ventilation of the larger hole, the more efficient size of the kibbles (hoisting buckets) and other equipment which can be used in it, the additional room for concreting operations and insertion of caisson rings, and the possibility of using orange-peel grabs if desired. On the other hand, an increase in diameter beyond 1.3 m ($4^1/_4$ ft) does not appear to give any great constructional advantage (see Fig. 11-14. pages 69, 73, 77 and 78).

Lining

With the exception of wells sunk into consolidated rock, a lining of permanent materials is always necessary. This lining serves several pur-

poses. It is a protection during construction against caving and collapse, it retains the walls after completion, and it also acts as a seal to prevent polluted surface water from entering the well, and enables the aquifer from which the supply is to be obtained to be isolated and protected from pollution. It acts as a foundation and support for the well-top and any pump or other mechanism which may be fitted on completion, and it serves as an impervious lining to the storage reservoir which such a well is designed to provide.

From both a practical and an economical point of view, it is better that the permanent lining be built into position as construction proceeds, thus avoiding the expense of temporary supports and the danger of collapse which may occur when the temporary work is removed to make way for the permanent lining.

The various ways of lining wells may be classified under two heads : those in which the wells are built into their final position as work proceeds, and caissoning methods, in which the lining is built above its final level and sunk as a completed unit to its final position. It will usually be found that a combination of these two systems will produce the most effective results.

There are many materials suitable for linings, masonry, brickwork, steel, and timber all being used in various parts of the world, according to circumstances; but for widespread use there are very great advantages in plain or reinforced concrete.

Masonry and brickwork are widely used in many countries and can be very satisfactory if conditions are right. In bad ground, however, they both suffer from having a low tensile strength, and unequal pressures can make them bulge or collapse. Building with these materials is slow, particularly in the confined working room of a well; and a greater thickness of wall is required than with concrete, as a result of which a correspondingly greater excavation is necessary. There is always a danger of movement during construction in loose sands or swelling shales before the cement has set; similar movement is prevented in a concrete lining by leaving the form in place to support the lining until the concrete has attained a high strength. Skilled masons, suitable stone, or well-fired bricks may not be readily available, whereas it is relatively easy to train unskilled workers to place concrete, and sand and gravel can usually be found within reasonable distance of a well site.

Steel linings are rarely used, because of their high cost, short life, and (except with very heavy sections) liability to bend. Timber is a most unsuitable material on account of its short life and its liability to rot, harbour insects, and taint the water. Also cross-members inside the well—necessary for strength—reduce the effective diameter; and it is almost impossible to make a lining sufficiently impervious, even when new, to keep out polluted surface water.

Fig. 12. SECTION OF WELL SHAFT: FIRST LIFT

Plumbing Peg

Temporary shutter to protect the well mouth

Ground level

12"

6"

8 th

7 th

6"

6 th

7 No 3/8" diameter M. S. Rods

5 th

3"

4 th

4' 0"

Supporting Pins

15' 0"

3 rd

Curb

12"

2 nd

1st set of shutters

Loose earth filling

WHO 9149
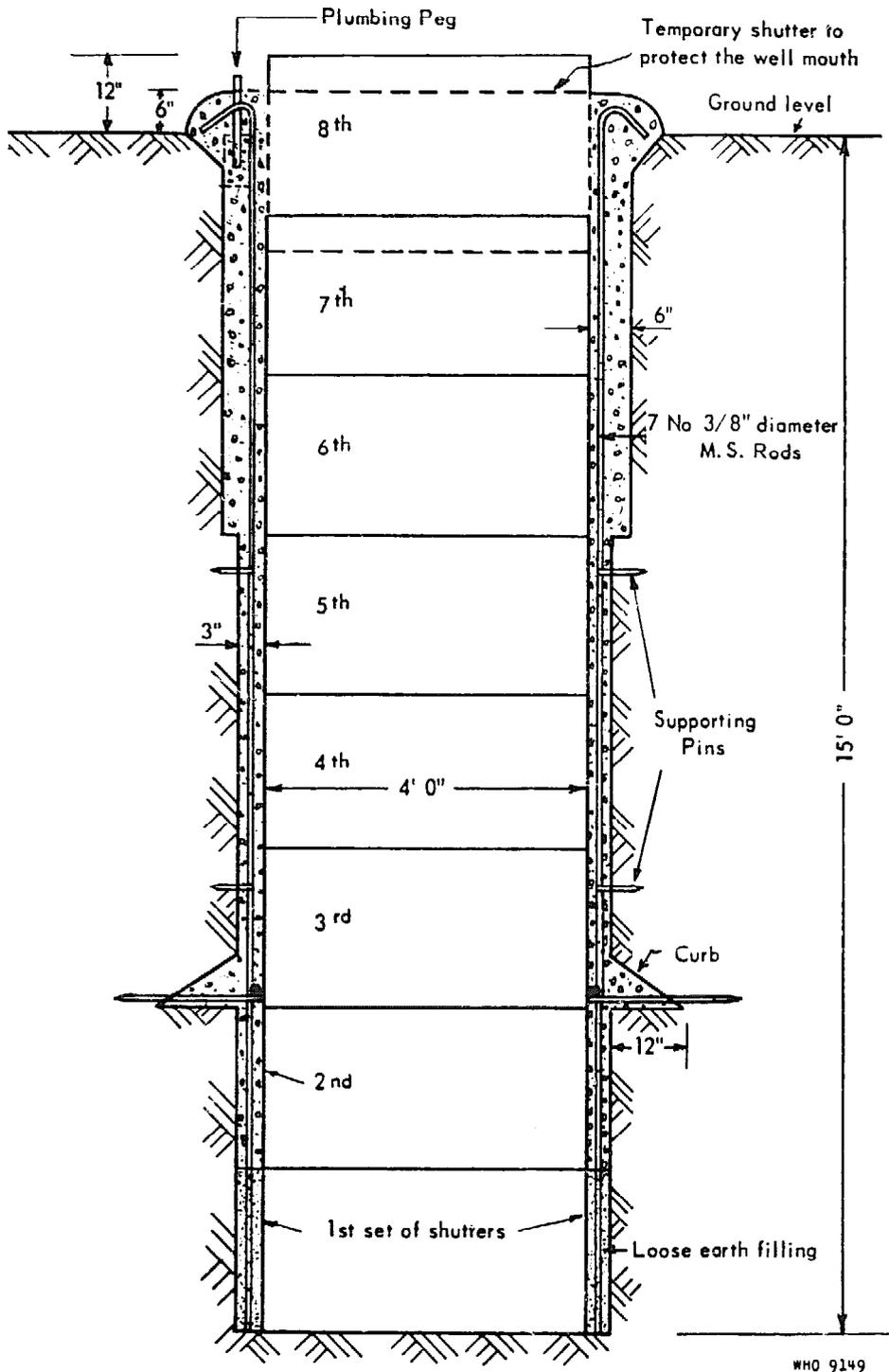
Scale : $\frac{1}{2}$ in. = 1 ft

Concrete, on the other hand, can be placed quickly by unskilled labourers, provided that they are adequately supervised; requires only a small thickness (8 cm, or 3 in., in good ground to a maximum of 12 cm, or 5 in., in bad); can be precast into caisson rings at the site, on the surface, in simple moulds; and makes a continuous, impervious lining, strong enough to support itself and any superstructure required. It adapts itself to the face of the excavation and can be made porous opposite the producing aquifer to act as an entrance screen.

Construction

Details of the equipment used and the sequence of operations in open well sinking are given in Annex 5, page 276. Briefly, the method of construction is as follows (see Fig. 12).

In normal ground (i.e., unconsolidated formations without any special hazards such as swelling shales or running sands) the shaft is sunk from ground level to the top of the aquifer by the method known as " alternate sinking and lining ". The hole is excavated and trimmed to a diameter of 1.4 m (4½ ft) and a depth of about 4.5 m (15 ft)—less if the ground is at all weak or if the ground-water level is less than 4.5 m (15 ft) deep. At that depth a curb or shoe is undercut into the side of the well about 30 cm (1 ft) deep all around; and, after the reinforcing rods have been placed into position, the section of the well is concreted by pouring behind metal shutters, which are added one by one from the bottom of the excavation as the lower section is filled. When this operation is complete, the result is a section of reinforced concrete lining 8 cm (3 in.) thick, 1.2 m (4 ft) in internal diameter, supported not only by its friction against the surrounding soil, but also on a reinforced concrete ring of 2-m (6½-ft) outside diameter.

Leaving the metal shutters in place, a further section of 4.5 m (15 ft) or less is excavated below the first and is in turn curbed and concreted, leaving 10 cm (4 in.) below the first curb to be hand-built with small concrete blocks joined with cement and mortar. Sinking is continued in this way until the water-bearing strata are reached; and, in effect, the well now consists of a series of self-supporting cylinders from the surface to the aquifer, with an impervious joint between each.

From this depth onward the caissoning method is adopted. The caissons have been cast in moulds on the surface during the sinking and lining operation and should now have attained their full strength. They consist of concrete cylinders each 61 cm (2 ft) high, 1.2 m (3 ft 10 in.) in external diameter, and 11 cm (4½ in.) thick, with provision for four longitudinal bolts. These caisson rings are lowered singly into the lined well, and each is fastened by four 16-mm (5/8-in.) diameter bolts to the ring below. A second cylinder is thus assembled vertically inside the

first lining, but free to move downward as soil is excavated from below. One man only can work within the caisson ring, which has an internal diameter of 93 cm (3 ft 1 in.); and the depth to which the caisson can be sunk depends on the depth of water which cannot be removed by bailing. When the water-bearing formation consists of sand and gravel, or other loosely bound materials, pumps should not be used at this stage of the sinking since, if too much water is extracted, caving will almost certainly take place as the water-bearing materials are drawn into the well from outside the caisson. Even in a firm water-bearing stratum, it is important to avoid excessive pumping, which may produce similar results.

Obviously, with a large well-sinking programme, work must go on all the year round, and wells frequently have to be sunk when the water-table is high. All programmes should allow for deepening to take place when the water is at its lowest, and the method described above lends itself particularly to this. It is customary to leave a number of caisson sections projecting upward into the lined portion of the well so that in the dry season the team has only to continue excavation to the appropriate depth when the caisson drops into its final position.

Another advantage is the verticality of the caisson which follows automatically if the top lining has been plumbed properly, according to the method described in Annex 5, page 276.

According to the nature of the aquifer, a well may be designed to admit water either through the walls or through the open bottom. When the walls are used—and this is the more usual method—the caisson rings opposite the aquifer are made of porous concrete, which is described in Annex 5 (see page 294). In porous-walled wells the bottom is frequently concreted to prevent upward movement of soil and to facilitate cleaning.

Occasionally, circumstances may make it desirable to draw water from the bottom only; an instance of this is when the aquifer is of very fine sand which would be drawn into the interstices of the porous concrete and either cause caving by the removal of the outside material, or clog the walls and prevent water from entering. In such a case, the caisson is made of normal concrete throughout; and, when the final depth has been reached, it is usual to place a filter of graded layers of gravel in the bottom to prevent the sand from being drawn upward into the well with the water. Requirements vary with circumstances, but a common gravel filter of this nature consists of 15-cm (6-in.) layers of 6-mm ($\frac{1}{4}$-in.), 10-mm ($\frac{3}{8}$-in.), and 12-mm ($\frac{1}{2}$-in.) gravel, the smallest at the bottom, with about 8 cm (3 in.) of 20- to 25-mm ($\frac{3}{4}$- to 1-in.) gravel to protect the surface of the filter. Each layer is carefully placed by hand and levelled off before the next size is added. In addition to this gravel filter, it may be desirable to lay over the bottom of the well a precast concrete grate, as shown in Fig. 17 and 18 (see pages 81 and 82).

A further purpose of this graded filter and the concrete grate is to reduce the " critical head " of the water in the well. This critical head is the maximum difference possible between the water levels outside and inside the well without movement of the aquifer particles. If it is exceeded, these particles are drawn in with the water, and caving can result. When a pump is fitted to the well, overdrawing (which means withdrawing water at such a speed that the critical head is exceeded) can be avoided by a proper positioning of the pump suction; but, with an open well when water is bucketed, it may be impossible to prevent the population from emptying the well completely if their needs demand it. When water is wanted from a level considerably below the watertable, therefore, it is often desirable to increase the thickness of the gravel filter described to prevent overdrawing.

In favourable areas, sub-artesian aquifers may be found. In such a case pressure water from the aquifer is forced up the well, and the standing water level is considerably higher than the point of entry. In these circumstances it is usual to complete the whole well by the sinking and lining method without the use of caissons. Sinking stops once the top of the aquifer is reached; and, in order to avoid having unlined sections submerged by the rising water (which occasionally comes up very rapidly), the " lifts ", or lengths of sections between curbs, are kept very small once the aquifer is neared. Geological knowledge of the terrain and information from other wells in the vicinity will usually allow the depth of such aquifers to be estimated fairly accurately. A graded gravel filter in the bottom of a well with a sub-artesian rise will usually be found of value.

Procedure for shallow wells (in firm ground formations) : Another procedure which is commonly used in many parts of the world for the construction of shallow wells may be briefly described as follows :

(1) The hole is excavated to the desired diameter and depth, or to a point where the ground appears unstable and cribbing becomes necessary in the hole to support the walls. In loose soils, dug wells must be cribbed in order to protect the men who are working inside the well. Cribbing material can be rough lumber and logs cut from any wooded area. Tight cribbing helps to keep out the ground water, allowing the well to be dug deep into the water-bearing formation.

(2) The material excavated is placed in boxes or buckets and pulled out with ropes from above. Usually one box or bucket is being emptied while another is being filled.

(3) When water is reached, it will be necessary to bail the water out of the well along with material excavated. The more efficiently the well is kept dry (of course, within the limitations mentioned in the preceding paragraph), the deeper it can go into the ground water and, therefore, the more water it will give.

## Fig. 13. DUG WELL WITH PROTECTIVE CASING AND PLATFORM
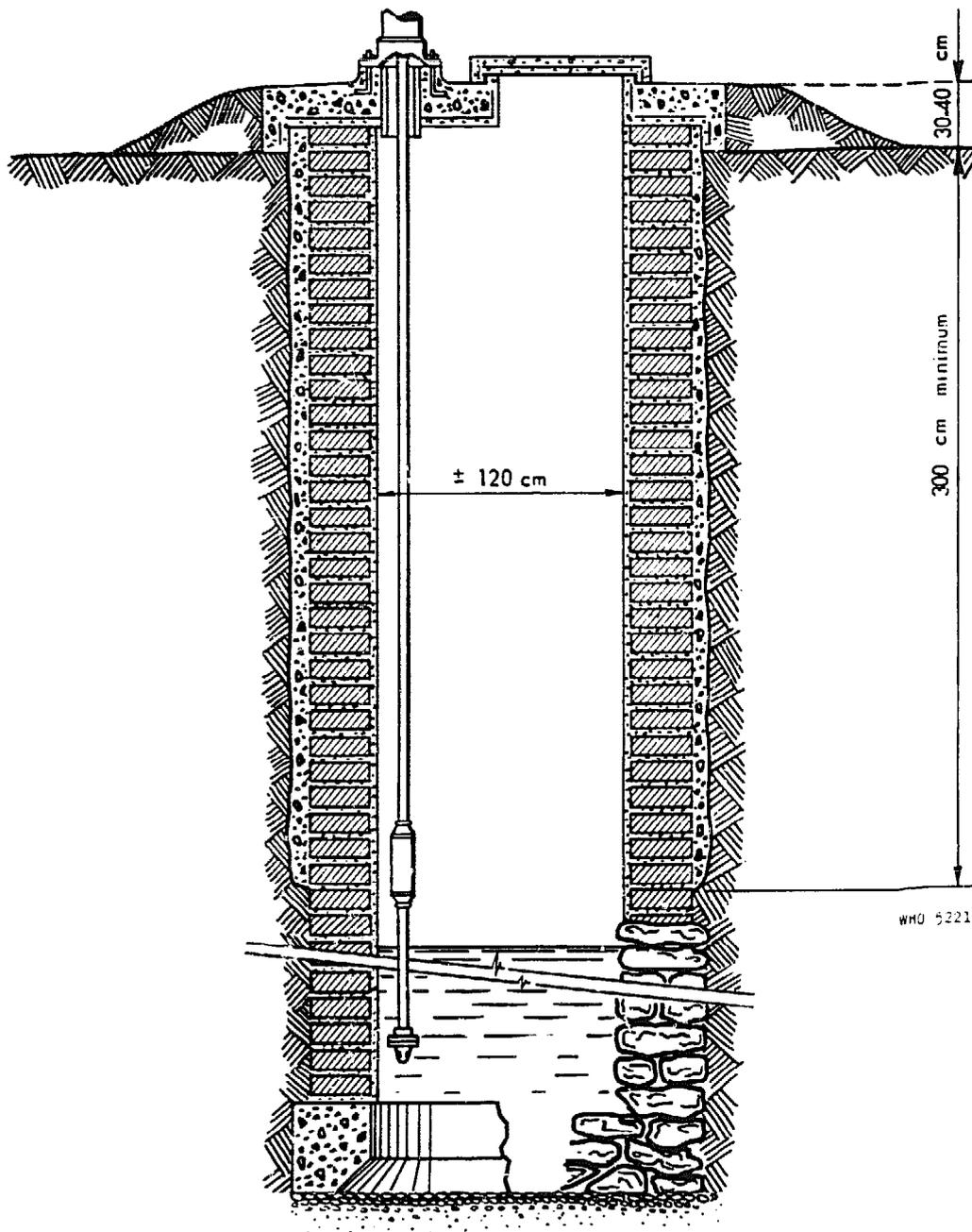
This figure shows a dug well and an outside protective cover of concrete.   At the well bottom are two different types of construction; one, built-up, round stones offering a filter wall, and the other, a concrete shoe.   Stones must be laid up after the well is completely excavated, and are practical only in areas of coarse sand and gravel.   The concrete shoe is employed where the well casing is sunk as the excavation progresses, and is usually more practical in fine sand.   A protective, graded sand filter should be built up in the bottom of this well.

Fig. 14. DUG WELL LINED WITH CONCRETE OR CLAY TILE

WHO 5222
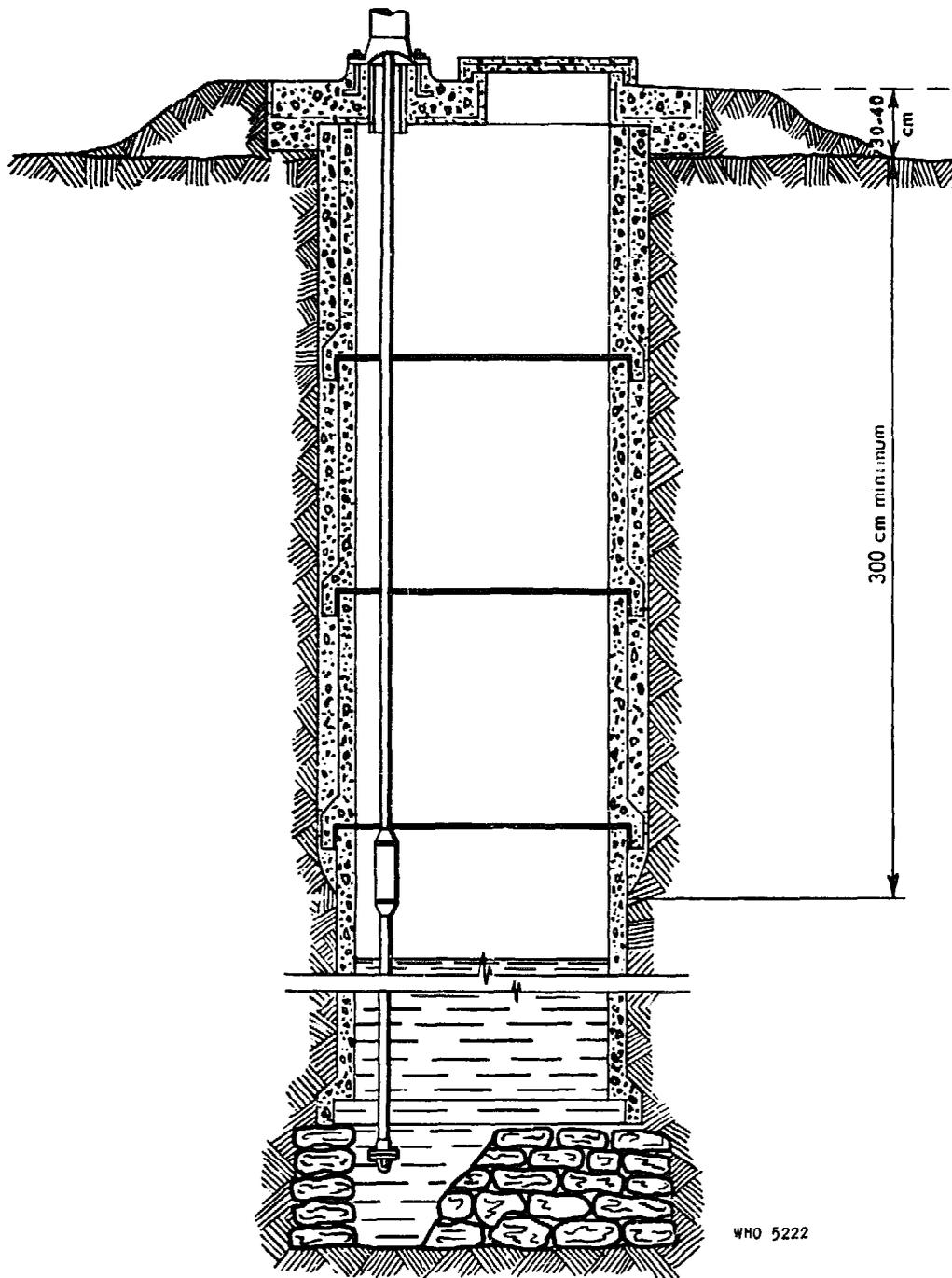
Concrete or clay tiles make excellent well casing and can be placed quickly and easily into the well by the use of a simple A-frame or other temporary structure for lowering tile into a well. Note the outside, protective layer of concrete which extends down to 3 m (10 ft) minimum to ensure water-tightness of the upper walls.

Fig. 15. RECONSTRUCTED DUG WELL WITH BURIED SLAB
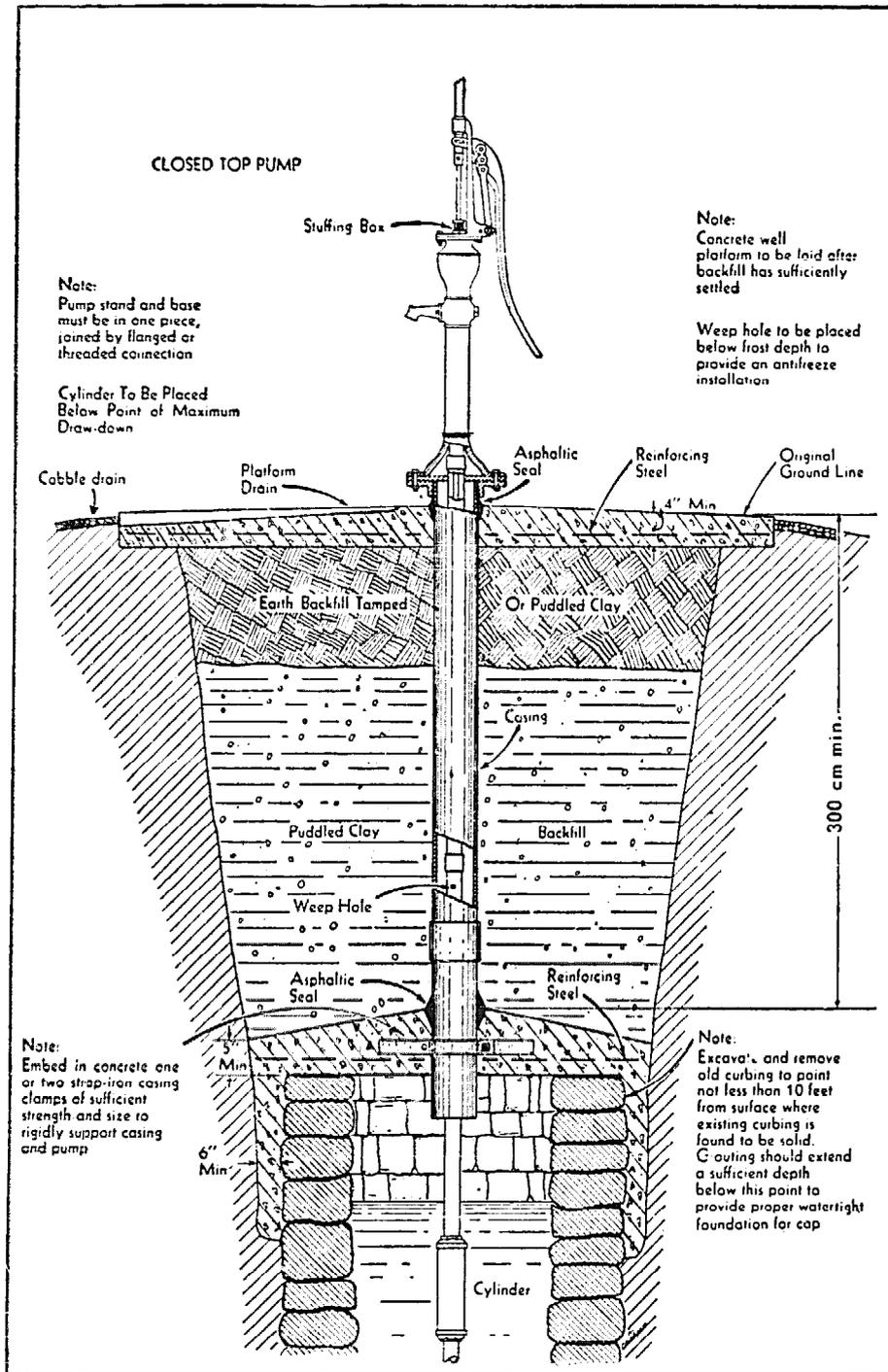
Reproduced from US Public Health Service, Joint Committee on Rural Sanitation (1950) *Individual water supply systems*, Washington, p. 25

(4) When the deepest possible point of excavation is reached, round stones should be laid around the wall (see Fig. 13) to form the first 0.5-1 m (20-40 in.) of well casing. Brickwork is built up to the top of the well, with extra heavy wall for the top 3 m (10 ft), well grouted to provide waterproof casing.

(5) To finish the well, either a bailing apparatus or a hand-pump and platform is installed, as shown in Fig. 13-15.

Procedure for deep-dug wells: Where wells are deep, the complication of cribbing and the danger of caving are great, so that the masonry casing is usually started after the excavation is about 5-6 m (16-20 ft) deep. It is built up to ground level and maintained there; from then on, it descends under its own weight as excavation continues (see Fig. 16). This system gives protection to those working in the well.

Fig. 16. DUG WELL: CASING DESCENDING WITH EXCAVATION

WHO 5226
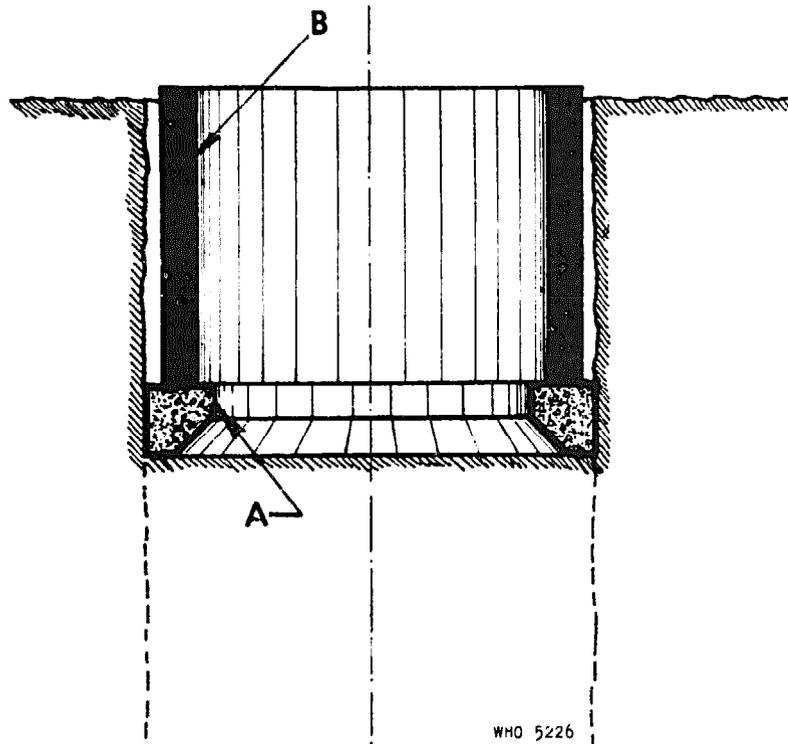
A = Reinforced-concrete shoe   B = Concrete or masonry casing

Large-diameter dug wells

Large-diameter dug wells are usually very shallow, 15-20 m (50-65 ft), and are built in order to provide large water-storage capacity. This is

Fig. 17. AMAZON WELL

DETAIL H DETAIL G

DETAIL F

SECTION C-C

SECTION B-B

CROSS-SECTION A-A   CROSS-SECTION D-D
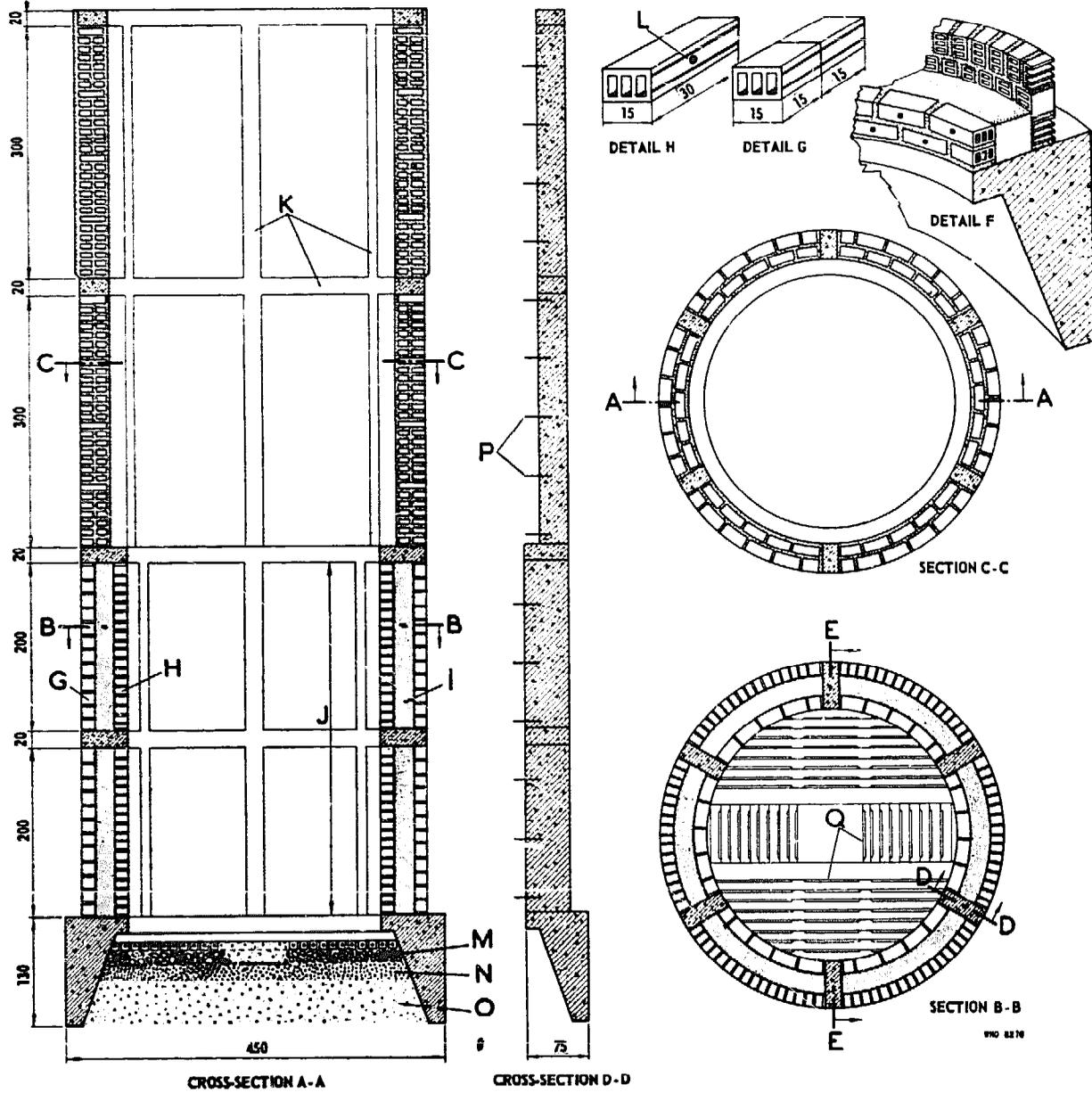
The scale used is in cm.

A — E = Cross sections
F = Reinforced-concrete shoe
G = Hollow bricks laid sideways. Water enters the filter section I through the holes in the brick.
H = Hollow bricks laid flat. Water enters the well through small holes designated by L. See detail H and F.
I = Sand filter section between brick walls

J = Height of filter section, varies with depth of penetration into ground water
K = Reinforced-concrete beams
L = Small perforations through bricks H. See detail F.

M = Layer of round stones
N = Layer of gravel
O = Layer of coarse sand
P = Iron steps, 50 cm (20 in.) apart
Q = Grate made of concrete beams (see fig. 18)

necessary when water is drawn out by mechanical means and the water-bearing formation is not sufficiently porous to avoid excessive draw-down. The construction of such wells often raises difficult problems due, for example, to caving and heaving of side walls.

In the Amazon Valley of Brazil, the Serviço Especial de Saúde Pública has had a great deal of experience and success with a large-diameter dug well called the Amazon well (see Fig. 17, 18). An important feature of this well is the filter section in the walls which allows a large quantity of water to enter through the sides. The reinforced concrete columns and rings give it structural strength to resist heavy outside pressure when the well is drawn down. The build-up of a filter section of washed and graded gravel in the bottom is another important feature. This keeps sand from entering the well, and the precast concrete grate holds the filter in place.

Where possible these wells are located close to rivers or streams; and, even in fine sand, some wells are producing 700 litres (185 US gal.) per minute. One Amazon well in coarse sand is producing 1800 litres (475 US gal.) per minute. The average depth of the wells is 15 m (50 ft), with a static water level about 4 m (13 ft) below the pump platform.

These wells are dug by hand, utilizing divers with home-made helmets to whom air is pumped by hand and motor pumps. No difficulties have

Fig. 18. AMAZON WELL: GRATE BEAMS
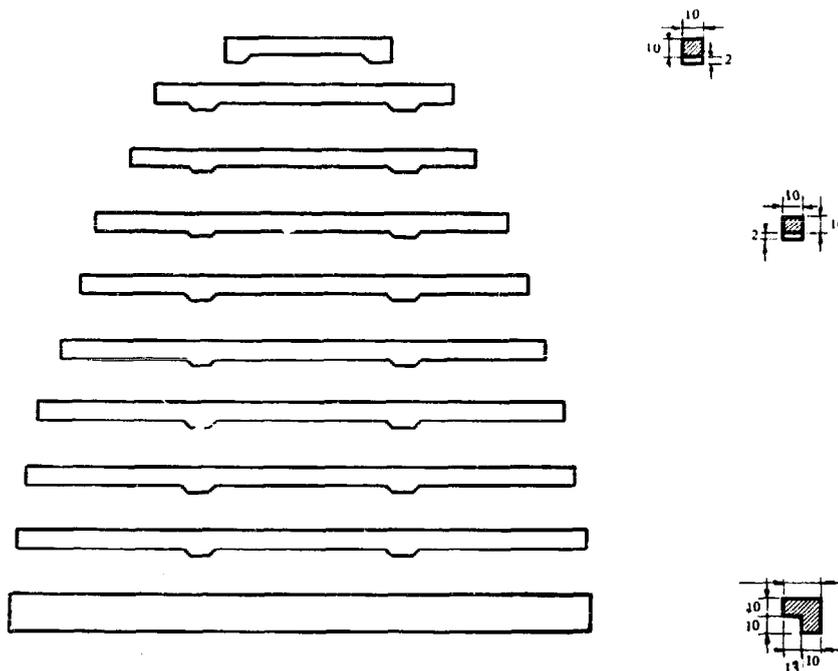
Note: See Fig. 17 for layout of beams.

been encountered in this method of construction except that it is slow, because digging under water is not very efficient, and the tremendous resistance between the soil and the casing keeps the latter always above the excavation, thus causing a great deal of sand to run into the well. In the end, several times the volume of the well is excavated. Jetting around the bottom of the well has given promise of facilitating the sinking of the casing. Mechanical excavating equipment would also speed up the excavating process. This well is relatively cheap where cement, reinforcing steel, and bricks are available and, of course, where a water-bearing sand is relatively close to the surface.

The yield of the large-diameter dug well can be increased considerably by developing a gravel pocket around the bottom filter section and by constructing laterals out from the well. This is accomplished by pumping large quantities of water into the well; it will soon begin to bubble up around the outside walls, and then graded gravel and coarse sand can be introduced all around the well. Large quantities of material are needed. While this is sometimes a laborious process, it is usually well worth the cost.

Extending laterals out from the well into the water-bearing strata is an excellent method of increasing its yield (see Fig. 19). For small works a heavy automobile jack can be used, but proper machines are available on the market for this purpose. These machines are also used for putting pipes under roads, buildings, etc., without disturbing the surface. A combination of jacking and jetting can be employed in one operation with advantage. Perforated pipes up to 15 cm (6 in.) in diameter, preceded by a drive point, and by a screen if desired, may be installed in this manner. Once the lateral is in place, provision should be made for developing the aquifer in its vicinity, and for periodic backwashing of these pipes. Laterals can be placed at various levels depending upon the characteristics of the water-bearing encountered. The construction of large installations of this type requires considerable judgement and engineering experience, and should not be attempted without consultation with competent hydraulic (water) engineers in central government public works administrations or specialized engineering firms.

Driven wells

Driven wells are constructed by driving into the ground with a hammer a pipe at the lower end of which a drive-well point has been attached (see Fig. 20, 21). These wells are usually from 2.5 cm to 10 cm, most commonly 3 cm (from 1 in. to 4 in., most commonly 1¼ in.). in diameter. On account of the ease with which these wells can be driven, pulled out, and put down again elsewhere, they are very popular in many parts of the Western Hemisphere, South-East Asia, and the Orient.

Fig. 19. LARGE WELL WITH HORIZONTAL PERFORATED PIPES

A = Stream or pond
B = Water-bearing formation, gravel or
    sand bank
C = Impervious stratum
D = Large-diameter well
E = Collection pipes (horizontal wells)
    headed by drive heads and provided
    with sections of perforated pipes.
    Lengths of these pipes to be decided
    after trial holes to see how far the
    gravel bank extends

F = Control valve
G, H = Connexions to receive hose from
    outlet H for backwashing collection
    pipes and for development purposes
I = Rising mains, pumps and motors
J = Check (non-return) valve
K = Valve controlling discharge of pipe
    leading to reservoir
L = Washout valve

Fig. 20. DRIVEN WELL WITH DROP-PIPE AND CYLINDER AND PROTECTIVE PLATFORM
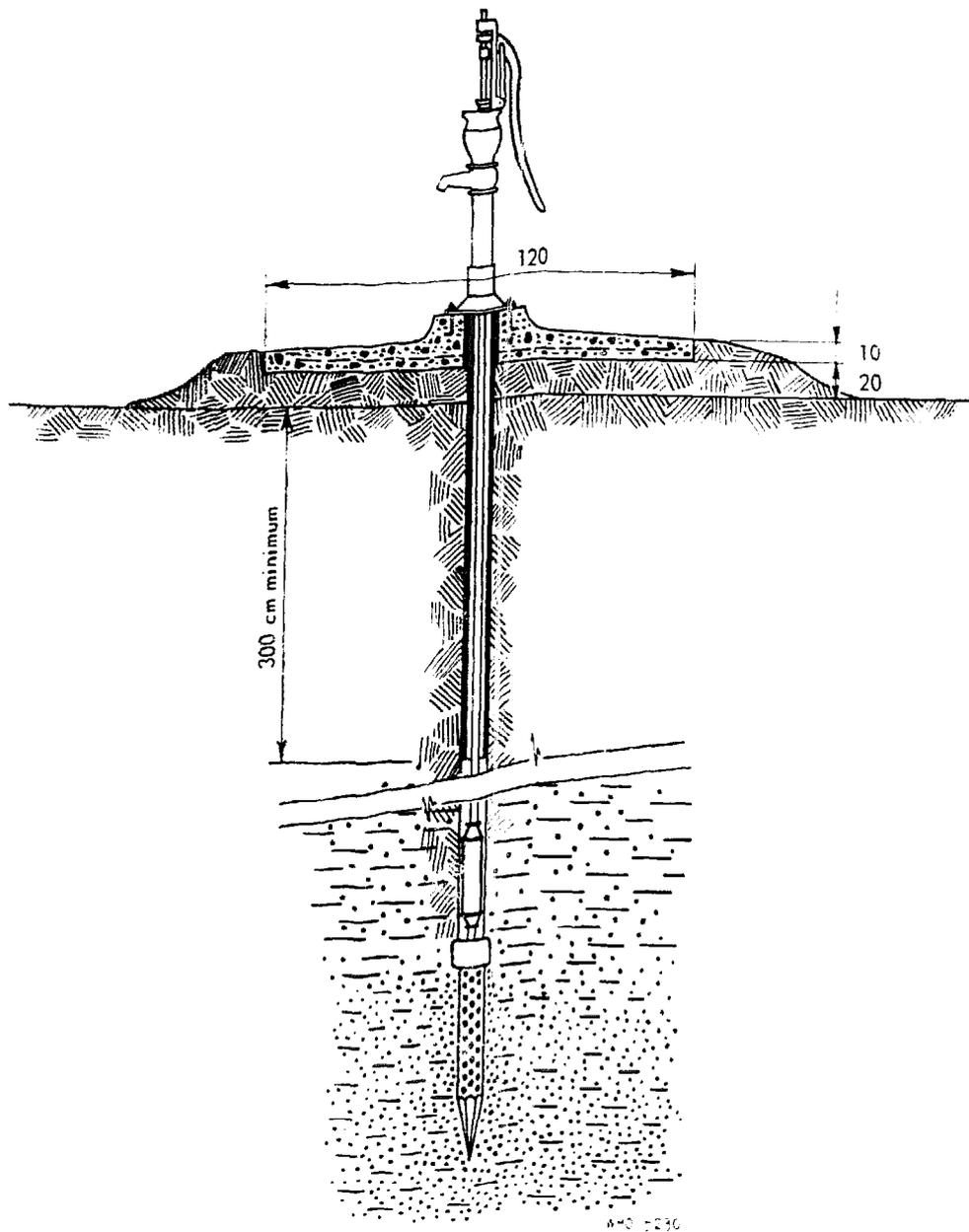
In areas with relatively coarse sand, driven wells can be an excellent and very cheap means of obtaining water. They can be driven rapidly and put into operation quickly. With proper technique, this well can be developed to increase its capacity. Note the water-tight casing which extends down to a minimum of 3 m (10 ft) below ground surface.

Fig. 21.   TYPICAL WELL POINTS
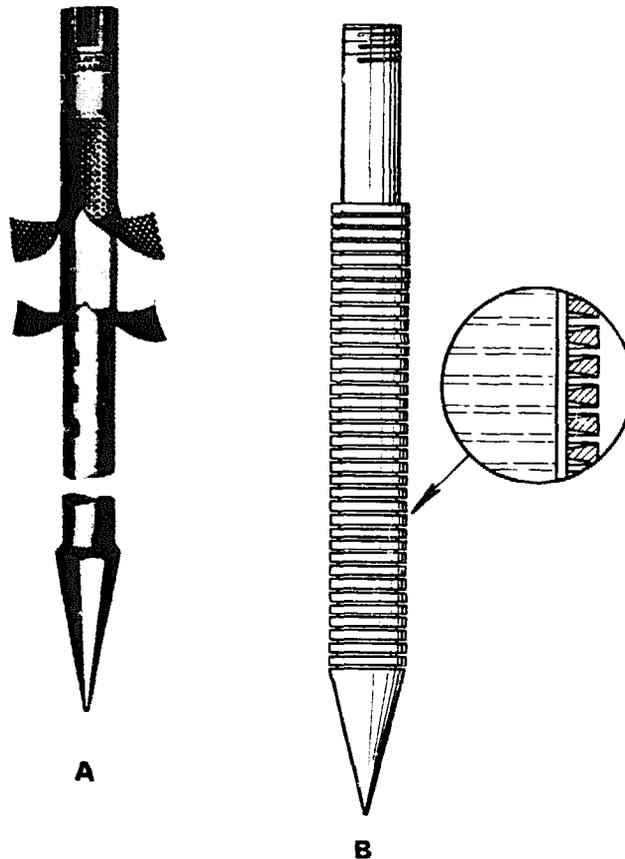
A = Common type of screen for well point.   It is reasonable in cost and, in a good water-bearing formation, it can give good results.   Over-pumping is apt to plug up the screen.

B = An effective type of well point.   It will not plug easily but is more expensive than common screens.   With proper development, large quantities of water can be obtained through such well points.

They cannot be put in hard, solid stone or hard-pan strata, or in heavy beds of clay; but they can be successfully driven through compact soils and even through chalk.   As in the case of bored wells, when boulders and rock are met it is best to pull up the pipes already in the ground and to try a new spot a little distance away.

The depth of ground water is another important consideration in the selection of driven wells in a given locality.   In individual installations where the ground water is very shallow, say within 7.5 m (25 ft) of the ground surface, the pump cylinder is usually attached directly to the top of the rising pipe.   The total depth of such wells seldom exceeds 10-15 m (33-50 ft).   For larger installations and under similar circumstances, a well-point system, designed as shown diagrammatically in Fig. 22, can deliver relatively large quantities of water from a shallow aquifer.

Fig. 22. WELL-POINT SYSTEM
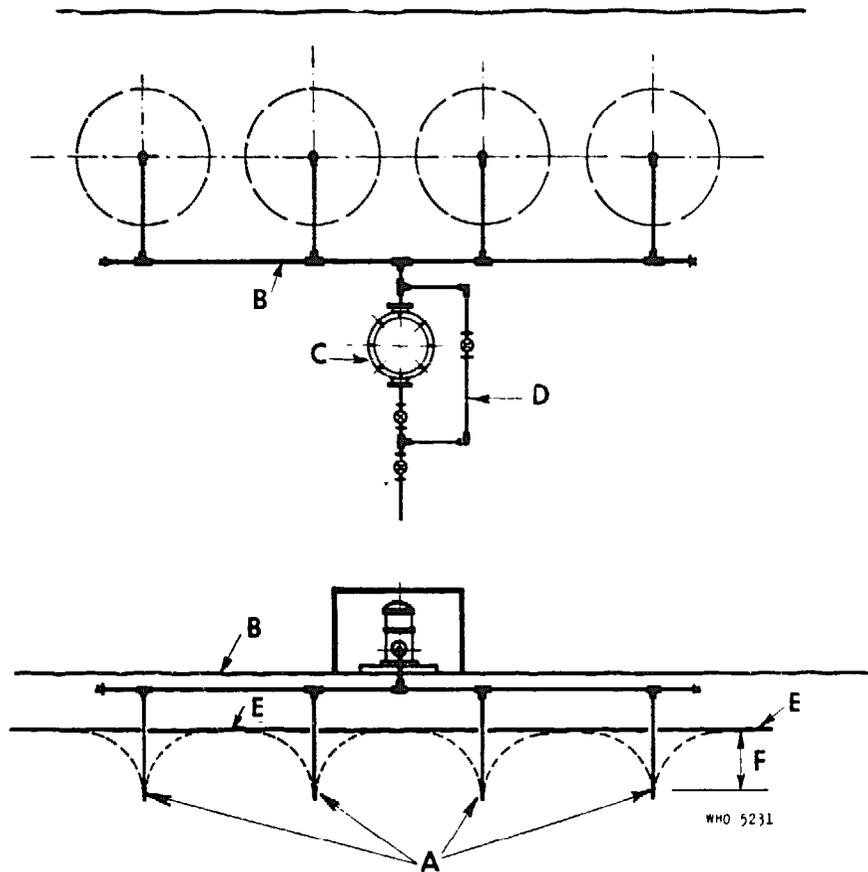
A = Well points properly spaced so that there is no interference between their circles of influence
B = Pumping header with allowance for future expansion in both directions
C = Pump
D = Priming line
E = Water table
F = Draw-down

Equipment and tools

Driving equipment and tools are simple and easy to operate. A typical set for driving 3-cm (1¼-in.) pipe includes :

Equipment

15 m (50 ft) of 3-cm (1¼-in.) wrought-iron pipe, extra heavy, with couplings provided
1 pitcher-spout pump, tapped for 3-cm (1¼-in.) pipe
1 drive-well point, 3 cm (1¼ in.), with jacket length 1.2 m (4 ft), with openings smaller than 0.4 mm (about 1/64 in.)

1 pulley bar, 3 cm × 1.4 m (1¼ in. × 4½ ft), approximately
1 driving monkey, 35-45 kg (80-100 lb.)
15 m (50 ft) of cleaning-out tubes, 1.3-cm (½-in.) diameter, in assorted lengths
1 pair of driving clamps, 3 cm (1¼ in.)
9 m (30 ft) of 2-cm (¾-in.) manila or cotton rope
1 plumb bob, line and winder, 15 m (50 ft)

Tools

1 pipe cutter, 0.3-5 cm (⅛-2 in.)
1 adjustable screw spanner, 25 cm (10 in.)
1 chain wrench, 0.3-3.8 cm (⅛-1½ in.)
1 25-cm (10-in.) file
1 set of stocks and dies, 1.3-3 cm (½-1¼ in.)
1 pipe wrench, 1.3-5 cm (½-2 in.), 46 cm (18 in.) long
1 side-cutting pliers, 20 cm (8 in.)
1 adjustable end-wrench, 25 cm (10 in.)
6 screwdrivers, assorted sizes
1 hammer, machinist, 340-g (12-oz.) weight
1 8-m (25-ft) flexible steel measuring tape
1 1.5-m (5-ft) crowbar, wedge point

Spares and miscellaneous

1 pipe cap, 3 cm (1¼ in.)
1 driving cap, 3 × 8 cm (1¼ × 3 in.)
2 spare cutting wheels for pipe cutter
1 3-cm (1¼-in.) plug tap
1 3 × 1.3 cm (1¼ × ½ in.) reducing socket
1 tin of red lead, 1 kg (2 lb.)

For driven wells 3 cm (1¼ in.) in diameter and 15 m (50 ft) deep, the cost of the above equipment would be approximately US $325 in 1958 in North America or Western Europe. This price is given, as a rough indication only, for engineers and administrators contemplating a programme of construction of such wells.

Technique

Although the methods used for driving wells vary considerably in their details, a typical technique of installation may be briefly described as follows.

The driving clamp is fastened to the drive point or perforated pipe. The monkey or hammer is slipped on to the pipe above the clamp, and the pulley bar is inserted in the pipe. A rig made of local wooden or bamboo poles may be set up for holding the pipes in a vertical position. A small hole 50-80 cm (20-32 in.) deep is dug in the ground by means of a crowbar at the selected spot.

Driving begins by pulling on the ropes, raising the monkey and, then, letting it fall on the clamp. Care must be taken at all times to keep the pipe vertical. This may be checked by means of a plumb line. When the

clamp reaches ground level, driving is stopped; the clamp is loosened and raised about 30 cm (12 in.) if the soil is hard, 50-60 cm (20-24 in.) if driving is easy through soft soil; and operations are resumed. When the first pipe has penetrated the ground to such a depth that there is no more headway for the monkey to work, a new length of pipe is added. To ascertain whether water has been reached, the plumb line is frequently lowered in the pipe. This also helps to determine whether earth or sand has penetrated to any appreciable extent in the pipe through the screen or perforations. When this happens, the dirt may be removed by means of the small cleaning-out tubes and a hand-pump.

After the water-bearing stratum has been reached, it is advisable to continue driving operations to such a depth that the well will never dry up, even in dry seasons. The pump may then be installed and the well completed.

To start the pump, it is necessary to fill the suction column with clean water and to exhaust the air which is in it. The water coming out of the well will be muddy at first, but will clear up after an hour or so of vigorous pumping.

In order to ensure a steady flow of water in the future, it is necessary to " open " the water-bearing formation in the vicinity of the drive point by removing its content of fine earth or sand particles. When the ordinary pitcher pump is used, this may be achieved by raising the handle high for a brief moment, thus allowing the water in the suction column to drop suddenly, and then resuming the pumping immediately and vigorously. With this sudden drop, the pipe's water rushes out of the screen at the bottom of the well and shakes and disturbs the fine particles surrounding the pipe. Such action facilitates the removal of the fine particles when pumping is resumed, as the well water will be seen to remain muddy for a while. This process should be repeated several times before the well is considered to have been completed.

Various other methods may be used for developing or finishing wells in sand and gravel formations. One of the simplest and most common methods is over-pumping, i.e., creating a draw-down much in excess of that which will be maintained in future operation. This system, while not fully effective as a development procedure, has the advantage of clearing fine particles from the well and its immediate surroundings and of providing useful data with respect to the capacity of the well. It may be used only on small, low-capacity wells driven into fairly well-graded formations. Over-pumping should not be done and may even be detrimental when the formation is uniformly fine and made of silt or clay, because it may result in considerable caving of the ground surrounding the well. Other methods of development, using compressed air, surge plunger, or back-washing, require study and much experience on the part of the driller or engineer, and should not be attempted lightly.

It is sometimes necessary to lift the pipes or to withdraw them completely from the ground. This happens, in the first instance, when they have been driven by mistake beyond the water-bearing stratum. In other cases, the soil may prove too compact, or boulders may have been encountered. Finally, no water may have been found within the permissible limit.

The pipe can readily be withdrawn by disassembling the monkey and pulley bar. By means of a crowbar or strong wooden log passed below the clamp and used as a lever, it is possible to pry the pipe out of the ground. The monkey may also be used in a reverse direction for the same purpose.

Jetted wells

With a small amount of pumping equipment, it is possible to sink wells to considerable depths very rapidly by the jetting method. Depending on the soil and the amount of water that can be pumped, a fairly large-diameter casing of 25-38 cm (10-15 in.) can be sunk 50-100 m (160-320 ft), thereby making it possible to install larger screens and pumps. Jetting is highly recommended for exploration and for small tube-wells, provided that plenty of water is available for sinking.

Small-diameter wells

The system of jetting as used in India for small-diameter wells and described very well by Bose [a] has given excellent results. It is summarized below.

Equipment:

(1) Tripod of bamboo with 8 m (25 ft) of clearance
(2) Hand-operated lift and force pump (double-acting, with plunger 10 cm (4 in.) in diameter)
(3) 4 chain-type wrenches for gripping pipes
(4) 12 m (40 ft) of high quality hose, 3.8-cm (1½-in.) diameter
(5) Casing pipe, boring pipe, a swivel joint, steel cutter, pulley ropes, small hand tools.

For small jetted wells, 61 m (200 ft) deep, for example, excluding casing pipes which belong to the wells themselves, the cost of the above equipment would be approximately US $1100 in 1958 in North America or Western Europe. This price is given, as a rough indication only, for engineers and administrators contemplating a programme of construction of such wells.

[a] Bose, P. C. (1953) *Water-supply systems in rural areas, with special reference to West Bengal, India.* (Unpublished working document WHO/Env.San./36)

The jetting process :

(1)   Dig a hole 1.5 m (5 ft) deep over which the tripod is mounted; this gives a reasonable starting depth.

(2)   Attach the cutter to one end of a 3.8-cm (1½-in.) boring pipe, usually about 6 m (20 ft) in length; swivel to other end and place cutter end of pipe into the hole; suspend the pipe and swivel with pulleys from the tripod (see Fig. 23).   The swivel joint allows water to enter the boring

Fig. 23.   TUBE-WELL BORING BY WATER-JET SYSTEM
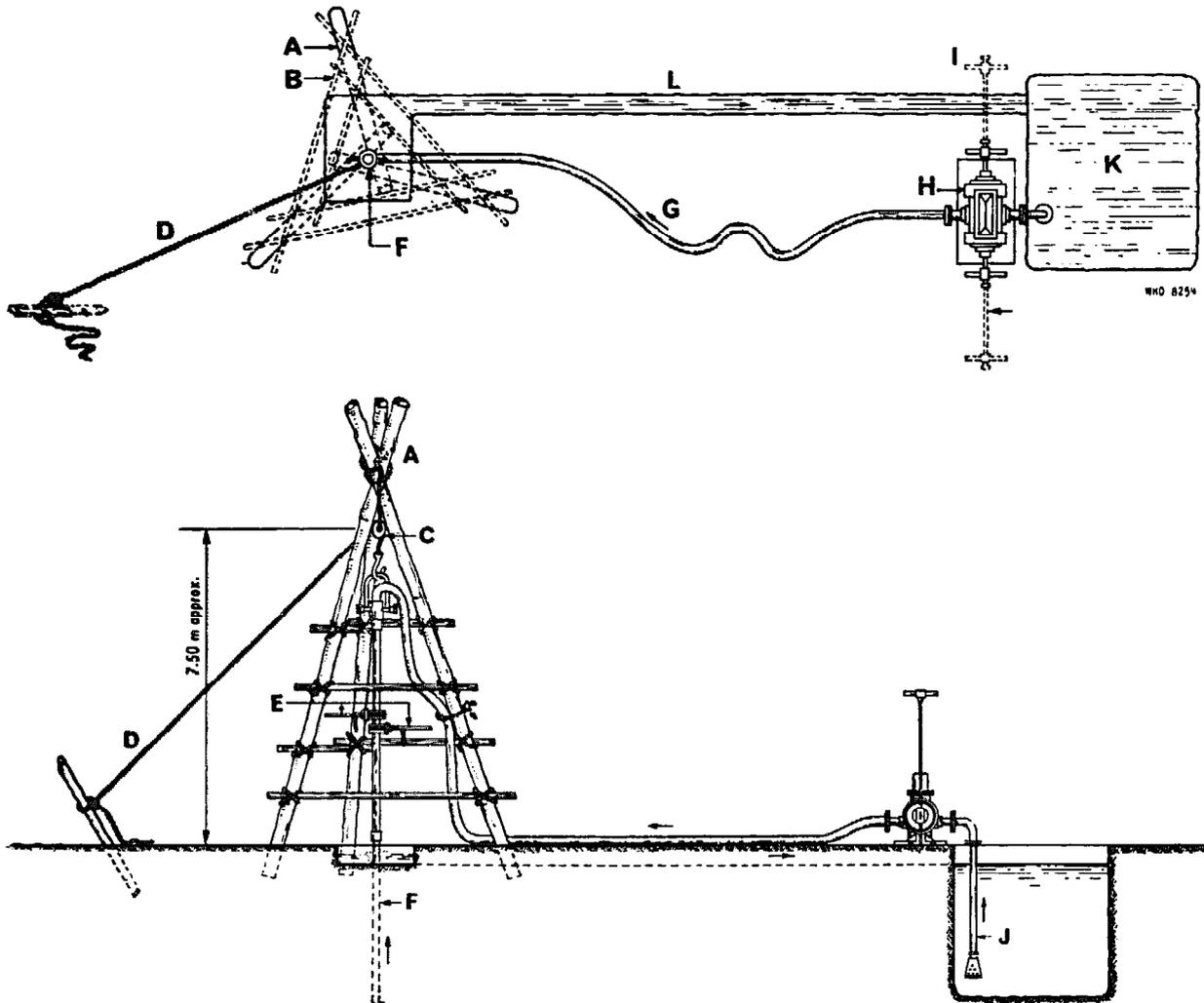
A = Wooden tripod	G = Hose
B = Bracing	H = Life and force pump
C = Pulley	I = Operating handle
D = Rope	J = Suction
E = Chain pipe wrenches	K = Water reservoir
F = 38-mm- (1½-in.-) diameter tube-well	L = Surface drain

pipe from the hole while, at the same time, permitting the boring pipe to revolve without leaking.

(3)   The hose is attached to the force pump which pumps water from a sump excavated in the ground near the well.   (The pump suction pipe must be held clear of the bottom and sides to avoid sucking up mud and sand.)

(4)   Jet-boring starts as the pumpers begin to force water into the boring pipe, at which point the men with the chain wrenches begin to turn the pipe.

(5)   With the pressure of the water and the twisting action, the bore pipe begins to descend, and the jetted water begins to boil up around the sides of the bore pipe.   This water is full of suspended matter and is really a light mud.   (*The more water that can be pumped through the pipe, the faster it will descend and the more and larger will be the suspended matter being washed out of the hole.*)   In a short time the first 6-m (20-ft) length of pipe will be at ground level.   The swivel is removed; a second length of bore pipe is screwed on; the swivel is attached to this new length of pipe; and the pumping, jet-boring process begins again.

(6)   One after another, the bore pipes are sunk until the desired depth is reached.   This can be ascertained by examining the borings that are coming out of the well.   In West Bengal the water-bearing stratum is a fairly fine sand with an effective size of from 0.16 mm to 0.20 mm.   When this stratum is reached, boring is stopped; but pumping continues at that level for some time to clean the whole well.

(7) Jetting water is re-used by letting the dirt and sand settle out in the sump.

Placing the screen :

(1)   The entire column of jet-boring pipe is now removed and the cutter is taken from the end of the bottom pipe.

(2)   The well screen is now attached to the first length of well pipe, and the process of lowering the pipe is repeated with pumping, but through the screen.   (Naturally there is little resistance in the recently jetted hole.)   The screen is open at the bottom; and, when it is in the position desired, a pre-seated plug made of lead is dropped into the pipe and closes the hole at the bottom of the well screen, sealing the bottom of the well.   A well point with a closed end may also be used, although sometimes a few feet of hole may be lost while raising the jet and lowering the well point.

At this stage of the process, when water is being pumped down through the well pipe and screen, washed pebbles can be dropped into the hole around the outside of the well pipe.   These are heavy enough to settle even against the upward stream of water, and the stream can be regulated to allow settlement.   These pebbles of round, washed gravel, from 1 mm to 4 mm in size, help to form a gravel pack around the well, thus reducing the possibility that fine sand may get packed up around the screen and enter the well, with a consequent cutting-down of capacity.   It should be added

that, where sufficient sand-free water is being obtained without the attempt at gravel packing, the methods that have proved successful should be followed. Where trouble is encountered in getting water from fine-sand strata, it will be worth while to experiment with gravel packing. It is highly important that round, selected, washed material be used.

(3) A 2-cm (¾-in.) pipe is now lowered into the well pipe to the bottom, and a strong jet is pumped. This is done to clean the inside of the well pipe and screen off any possible sediment, sand, or dirt.

Finishing the well:

(1) The space between the well pipe and the earth hole should be back-filled with compacted clay or concrete to prevent contamination from reaching the water table through this space.

(2) The well is now complete, and the hand-pump is installed and operated continuously for (at least) eight hours per day for three days to clean out the jetting water.

(3) A little hypochlorite should be introduced into the well, allowed stand for 24 hours, and then pumped out again.

(4) A watertight platform should be constructed to complete the well.

Jetting large-diameter casings

When casings 10 cm (4 in.) or larger are to be jetted, a tower such as that shown in Fig. 24 may be built of local, rough lumber; but, if many wells are to be constructed, a lumber or metal tower that is dismountable may be advantageous. If possible, the tower should be built as high as the length of the well casing so that, once the jetting operation starts, it will not stop until the casing is at the desired depth. This is very important because, as long as the casing continues to go down, no difficulties are encountered; but, once operations stop, it takes a tremendous surge of water and agitation to start the casing down again. This is especially true with casings 15 cm (6 in.) and larger. It has been found worth while and economical to build a high tower just to avoid stopping in the middle of the jetting operations to splice on more casing. Naturally there is a limit to the height of the tower. The problem of sticking casings of less than 15 cm (6 in.) is not so great, and the expense of a high tower is probably not justified for these sizes.

A large quantity of water is necessary; and, the larger the casing, the more water is needed. When one pump is not enough, more than one can be used in tandem. This type of construction must be carried out, therefore, near streams or rivers or other bodies of water. The use of sumps for settling out the heavier suspended material is a practical solution when only a limited quantity of water is available (Fig. 25).

Fig. 24.   JETTING A LARGE-DIAMETER CASING_(I)
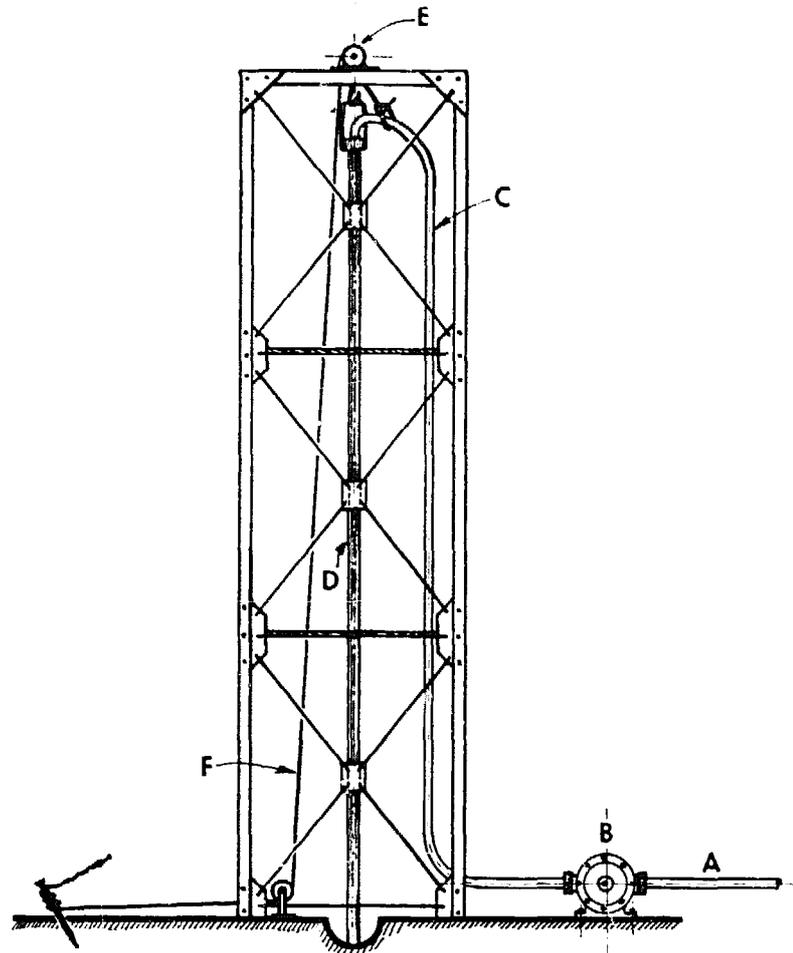
WHO 5235

A = Hose or pipe to ample supply of water
B = Large-capacity, portable, centrifugal pump
C, D = Hose to swivel joint and casing
D = Well casing
E = Block and tackle (size depends on weight of casing and hose)
F = Rope to block and tackle

First. a hole is augered into the ground about 1.5-2 m (5-6½ ft) deep at the point where the pipe is to be sunk.   This is done to get the casing started. If the area is new and nothing is known about its geological features, a 5-cm (2-in.) pipe is jetted down to open up the ground formations and to collect samples.   When the well depth is determined, the 5-cm (2-in.) pipe is removed, and a 15-cm (6-in.) casing and screen with a ball check

Fig. 25. JETTING A LARGE-DIAMETER CASING (II)

Line to hoist

Swivel

Pump

To water supply or sump

Washings   Washings   Clearer water for re-use

Water

Heavy material settles out here

WHO 9150

Casing

Screen

Ball check valve
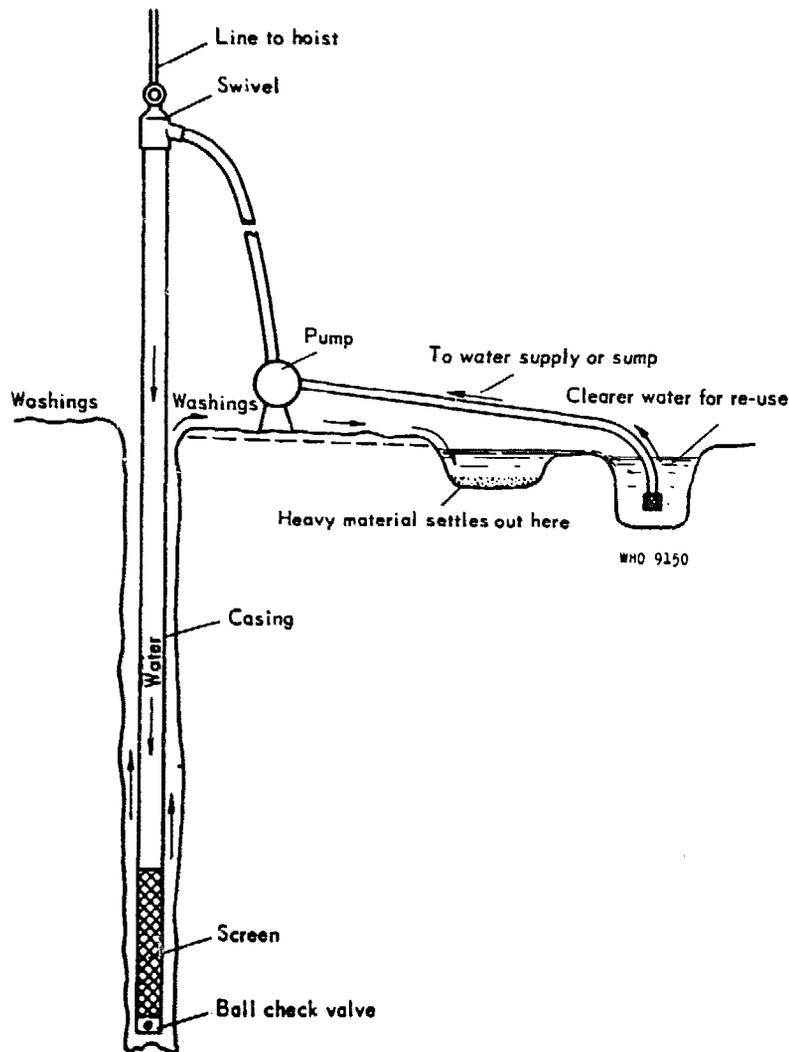
With ample pump capacity and water, 10- to 20-cm (4- to 8-in.) screens can be readily jetted to depths of 50 m (164 ft) or more in unconsolidated formations. This system is especially practical in broad river valleys or near streams.

valve are placed in position. The pump is started, and the casing usually goes down quite readily. It may be necessary to hold the pipe slightly off the bottom of the hole in order to get the jetting operation started. This reduces bottom resistance, and less water goes out through the sides of the screen. When the desired point is reached, the pumping continues and a gravel pocket is developed around the screen. As the water rises around the outside of the pipe, fine gravel and coarse sand are put in the annular space on the periphery of the casing. This material goes to the bottom

of the hole and begins to fill the void between the screen and the sides of the hole. As more material is put in, resistance to the rising water is increased; and, finally, the water will rise so slowly that no more fines are washed out. From then on, pumping is begun with a test pump to clean out the well and measure capacity. Surging might be required if the water-bearing stratum requires further development. This would allow more fine particles to pass through the screen. If the capacity is adequate, the annular space around the well casing is filled with sand up to a point 4 m (13 ft) from the surface; and a protective casing is placed in the top 4 m (13 ft).

If the pumping test proves the well to be inadequate, the casing and screen are removed. This is done by use of two auxiliary pipes of 2-cm or 2.5-cm (¾-in. or 1-in.) diameter which are jetted down on each side of the casing to the bottom of the hole. When this point is reached, pumping through the screen casing is begun. With a chain hoist pulling on the casing, the latter will usually come loose; and, from then on, the regular hoist will be able to complete the job of pulling it out. The pumping continues until the casing and screen are completely removed. Auxiliary jets can usually be stopped once the casing starts to move upwards.

Equipment

Pump, 8-cm (3-in.) discharge outlet, capacity 75 700 litres (20 000 US gal.) per hour against zero head
Extra strong, reinforced hose, 8 cm (3 in.)
Foot valve, 8 cm (3 in.)
Cutting bit for hard material
Fishtail bit
Swivel, 8 cm (3 in.)
A frame or tripod with winch and cable or tower
Pipe wrenches
Chain tongs
Clamp to hold pipes
Chain hoist
Hammer, 3 kg (6.6 lb.)
Small tools for engine and pump maintenance
Grease gun
Soil sample kit
Steel tape, 30 m (98 ft)
Small electric water-level indicator
Pipe-threading dies for sizes used
Hack saw with extra blades
Files for repairing threads of casing
15-cm (6-in.) auger to start holes
Shovels, picks, and tools for clearing
Wood blocks and planks for levelling and securing pumps and engines
Casing

Material

2.5-cm (1-in.) pipe for auxiliary, etc.

Fittings for 2.5-cm (1-in.) jet: two long-radius elbows, two couplings, one reducer
8 × 2.5 cm (3 × 1 in.)

2 valves, 8 cm (3 in.)

Fittings to hook two pumps in tandem

Well screens of various slot sizes, with jetting valves

Gasoline, oil, grease

For jetted wells 15 cm (6 in.) in diameter and 61 m (200 ft) deep, for example, the cost of the above equipment would be approximately US $3800 in 1958 in North America or Western Europe. This price is given, as a rough indication only, for engineers and administrators contemplating a programme of construction of such wells.

Selection of screen

The purpose of a screen is to permit ground water to flow with a minimum of resistance into the well hole while at the same time excluding fine sand. A good screen will pass up to 70%-80% of the water-bearing sand grains into the well. This statement does not apply, however, to sand formations of uniform size such as are often found in many areas of the Amazon Valley of Brazil and elsewhere.

Since the life span of a driven well is governed by the quality of its screen, it is important to select a screen not only because of its hydraulic characteristics, but also because of the quality of the alloy of which it is made. It is first necessary to make a sieve analysis of the water-bearing formation and to determine its thickness. From these data it will be possible to specify the size, shape, and number of screen openings, as well as the diameter and length of the screen desired, liberal allowance being made for loss of capacity and reduced life span due to incrustation or corrosion and to partial clogging of openings. Finally, the metal of which the screen is made should not be vulnerable to attack by the chemical action of the ground water or by the acids sometimes used to remove incrustations from such screens.

Bored wells

A simple method of construction of small-diameter wells of shallow depth is the use of an earth borer, also called earth auger (see Fig. 26, 27). First, a small hole 30-50 cm (12-20 in.) deep, and of sufficient diameter to allow the introduction of the borer, is dug in the ground with an ordinary pick or crowbar. From then on, boring proceeds to the desired depth.

7

The shape of the spiral allows the loosened soil or gravel to rise upwards. From time to time, the borer is raised out of the hole together with the soil extracted.

Fig. 26. TYPICAL BORING TOOLS
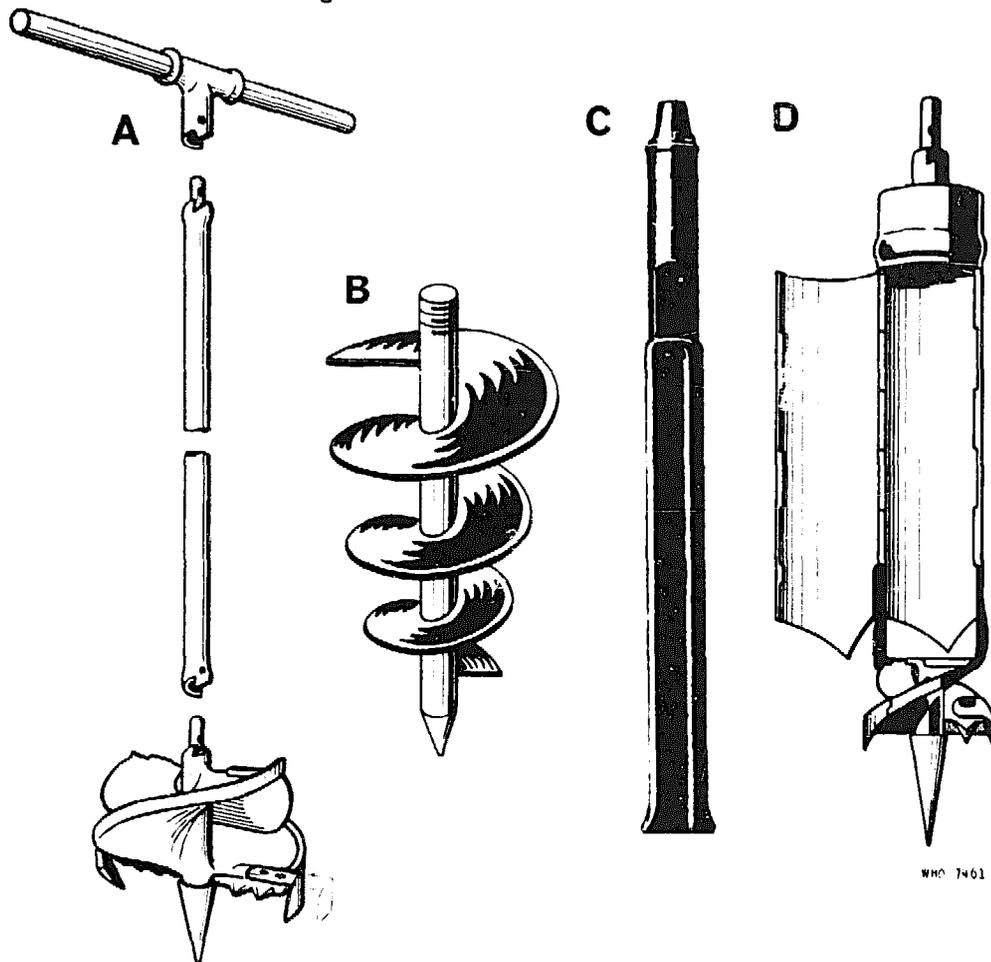
A = Tool for boring in top soil, clay, sandy clay, or formations that are not too hard or caving. Cutter (a) may be added to permit boring up to 8 cm (3 in.) wider than standard size

B = Spiral auger

C = Regular club bit for breaking through hard formations, loosening rock, and breaking soft rock

D = Tool for boring in soft, wet, sandy soils

The limitations of this method, which is usually a hand operation, are obvious. When hard underground formations, such as rock or stone, are encountered, boring is stopped and a new spot selected several metres away. This method is especially adapted to soft soil, chalk, limestone,

Fig. 27. BORED WELL WITH PROTECTIVE CONCRETE CASING AND PLATFORM
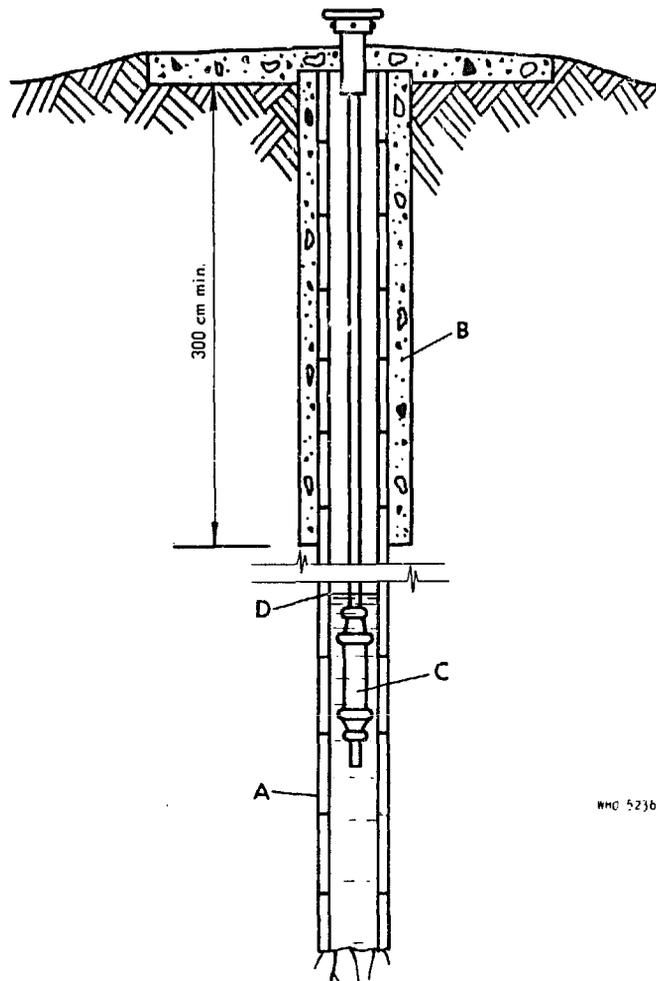
A = Clay tile lining, 10-15 cm (4-6 in.) in diameter
B = Protective concrete lining
C = Pump cylinder
D = Standing water level in well

Where soil is sandy or clay with no large boulders or hard rock formations, wells may be bored to considerable depths. Bored wells are reasonable in cost and can produce good results.

and alluvial formations which are devoid of large gravel and stones and can be easily penetrated.

Several accessories to the earth borer have been designed by manufacturers to facilitate boring, especially in soils containing either wet sand or loose gravel.   Some of them are shown in Fig. 26.

A typical set of boring tools for wells of 10-cm (4-in.) diameter or less includes :

1 drill, 10-cm (4-in.) diameter

1 one-piece 10-cm (4-in.) drill and deep-boring attachment

1 T-handle

15 m (50 ft) of steel rods for 10-cm (4-in.) drill

1 sand borer, 10-cm (4-in.) diameter

1 spiral point

1 chisel, 9-cm (3½-in.)

1 twist drill

2 extension cutters, for 10-cm (4-in.) drill

One complete set of boring equipment and tools for wells 15 m (50 ft) deep and 10 cm (4 in.) in diameter, including 10-cm (4-in.) pipe lining, would cost approximately US $300 in 1958 in North America or Western Europe. This price is given, as a rough indication only, for engineers and administrators contemplating a programme of construction of such wells.

Because of the rough handling and use to which the equipment is usually subjected in the field, a liberal number of spare items should always be at hand.

Once the hole is completed and the water-bearing stratum deeply penetrated, small-size pipes with screen or strainer attached are lowered into the hole, the pump is installed, and the well is completed by the construction of an adequate platform and the provision of drainage for surface water.

When the soil is so soft that it frequently caves in, pipes of a diameter equal to—or 1.3 cm (½ in.) larger than—the borer's nominal size are lowered as boring proceeds. The borer is passed inside the pipe and is provided with movable side (or extension) cutters (see Fig. 27, page 99) capable of cutting a hole 3.8 cm (1½ in.) wider in diameter than the borer, to allow the pipes to follow the borer as it descends.

In some parts of the world it is not uncommon to bore wells to 90-cm (36-in.) diameter, using a team of horses and augering equipment designed for such purposes.

Drilled wells

In this monograph, the term " drilled well " indicates that which is constructed with machines designed and manufactured for the purpose of drilling water wells. These machines can be described as being of two general types : (1) the percussion, and (2) the rotary.

The percussion drilling rig, also known as the " cable tool " rig, is the more common and more simple (see Fig. 28). It consists of a derrick and hoisting and control equipment, skid-trailer or truck mounted. The derrick serves as the elevated structure from which the drilling tools, well casing, screens, and all materials and equipment used in, or to construct, the well are suspended and manipulated. These rigs vary from the very small sizes to those which drill more than 1000 m (3300 ft).

Fig. 28. PORTABLE WELL-DRILLING RIG
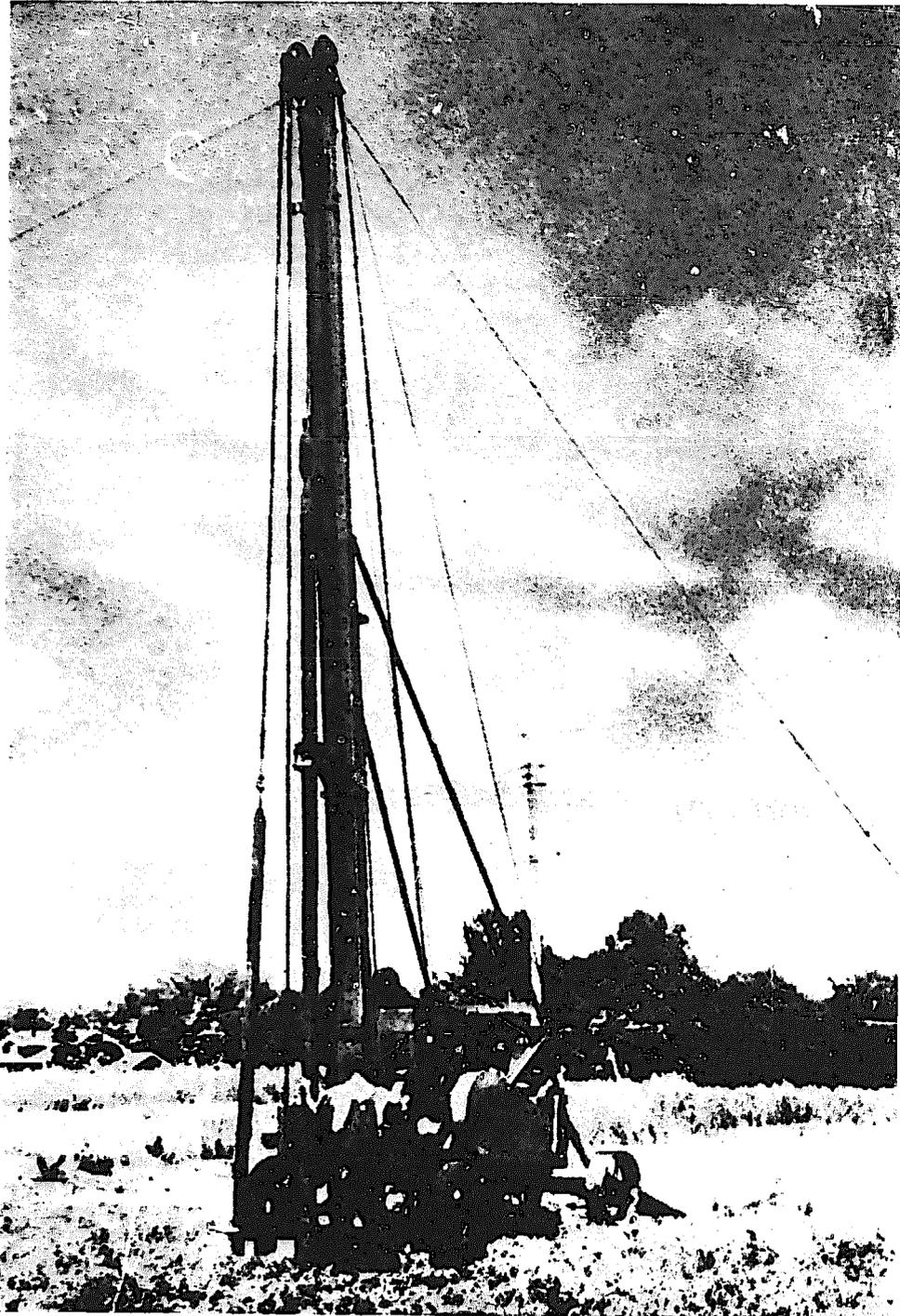
Reproduced from Bulletin 20-W-2 by kind permission of Bucyrus-Erie Co., New York, N.Y., USA.

Such drills can be transported on 1½-ton trucks and may be used for holes from 7.5 cm to 15 cm (3-6 in.) in diameter and up to 115 m (377 ft) in depth.

While all percussion rigs work on basically the same principle, i.e., the chiselling action of a tool alternately raised and dropped in a bore-hole, rotary rigs are much more varied in construction and operation, though all have the common feature that the bit is revolved in the hole.

A percussion bit only loosens the ground, and the loosened particles are brought to the surface by means of a bailer or similar tool; but the great majority of rotary rigs perform the two operations of loosening and removal simultaneously. In the normal, "straight", rotary process, mud is pumped down the centre of the drill-stem—the tube which communicates the rotary action of the turntable at the surface to the bit underground—and this mud in its return through the annular space between the drill-stem and the bore-hole walls performs two functions. The upward flow to the surface carries with it the loosened material from the bit, and the pressure of the flow forces mud into the bore-hole wall which seals and supports it, thus rendering casing unnecessary. In the "reverse-flow" method, mud is not normally used; but a stream of water flows down the annular space and up the drill stem. The increased velocity in the smaller cross-section of the drill-stem is caused by a pump which sucks water from the centre instead of a high-pressure pump which forces water down it, and by this method very rapid results can be achieved and large-diameter holes can be made. Another rotary method uses no water but utilizes compressed air to blow the material to the surface. In all these types of rotary drilling, a variety of bits is used, from the simple roller bit, for normal work, to the diamond drill, a bit which is tipped with industrial diamonds and which will penetrate the hardest rock formations.

Some of the advantages and disadvantages of percussion and rotary methods are as follows. The percussion rig is lighter and more portable and needs far less water than the rotary. The pumping or compressor units on rotary rigs are cumbersome and heavy; and the reverse-flow system, particularly, uses large quantities of water, which are not usually obtainable in the places where exploratory drilling is required. In addition, the material used on a rotary mud-flush tends to seal off the weak aquifers, which may be the principal or only sources of water coming into the hole.

On the other hand, the rotary method is normally much quicker, and holes of greater diameter may be put down in a shorter time, particularly when the work is grouped and a number of holes can be put down consecutively in one area without the dismantling and transport of all the equipment. In addition, more accurate information can be obtained from a rotary hole : coring is more positive and samples are taken more precisely; and electric logging devices can penetrate the walls of the hole—an impossibity with percussion drilling, in which the casing is lowered with the tools. One further advantage of rotary drilling is the ability to under-ream to more than twice the diameter of the hole to enable gravel walls to be built up round the screens.

For normal field production holes and normal exploratory work, the balance of advantage lies with the percussion unit; for multiple holes and very accurate exploratory drilling, particularly on accessible sites, a rotary unit will generally be found more useful.

Drilling wells is very specialized work, requiring considerable experience. This type of well construction should not be attempted without careful consultation with competent well-drilling firms or consulting engineers. Many governmental agencies have had sad experiences not only in attempting to purchase equipment and organize drilling crews, but also in contracting drilling firms without first investigating the firm and without being well enough acquainted with the problems involved.

All those constructing wells for community water-supplies will sooner or later be required to judge the possibility and practicability of drilling. Before any kind of recommendation is made, a thorough study of the problem with reference to local conditions must be carried out. It should be remembered that, without previous drilling history in the area, any attempt is a gamble, even though geological studies indicate the contrary. In rural areas not easily accessible for drilling equipment, this method should be employed after others have failed, and then only when careful investigation by experienced people indicates a good possibility of success.

It is recommended that those involved in the development of ground water (particularly when well-drilling is anticipated) should study, among other literature, the relevant references in this monograph.[5, 6, 13, 35]

Infiltration Galleries

Infiltration galleries are nothing more than horizontal wells which collect water over practically their entire lengths (see Fig. 29, 30). Where the construction of such galleries is feasible, a good and wholesome supply of water may be obtained.

Many towns and villages in the rural areas of less-developed countries are built along a river or a lake. When the stream beds or lake shores are sandy or gravelly, the possibilities of finding a gravel pocket along a bank are excellent. These may sometimes be seen from the stream or lake bed during low water, but are more often found by systematic exploratory borings along the banks.

The gallery is a simple means of obtaining naturally filtered water, and, for this purpose, it should be located 15 m (50 ft) or more from the bank of the river or lake. It is constructed by digging a trench into the water-bearing sand, then collecting the water in a perforated pipe or gallery (masonry-lined or unlined) which leads to a central casing from which the water is pumped out. The walls of infiltration galleries may also be built

Fig. 29.   INFILTRATION GALLERY
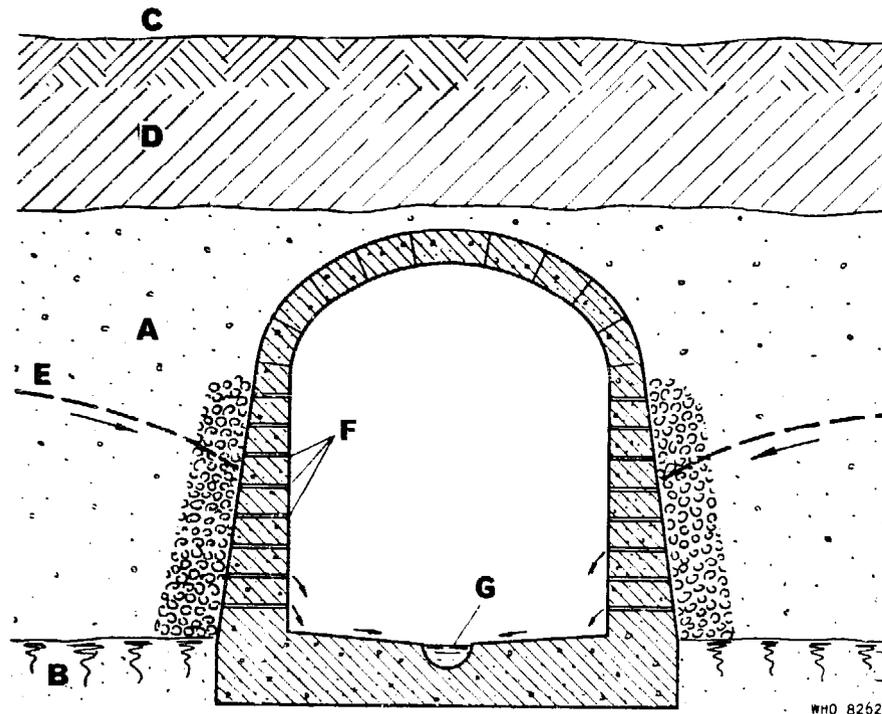
A = Water-bearing sand or gravel
B = Impervious formation
C = Surface of the ground
D = Top soil
E = Ground-water table
F = Staggered openings through walls
G = Collecting-trough conveying water to collection chamber or reservoir

of porous concrete. The length of the trench depends upon the amount of water desired and the size of the water-bearing pocket.

Careful tests to measure capacity should be made before constructing a complete gallery. The best galleries collect water well below the ground water level, thus making it necessary to de-water the working trench. This usually requires cribbing and de-watering pumps and therefore is more expensive than a simple bored or driven well. This system, however, offers better possibilities of obtaining large quantities of water if a suitable formation, such as a reasonably coarse sand, can be found.

An infiltration gallery may also consist of a tunnel driven into a water-bearing stratum. The tunnel may be so built as to lead the collected water out by gravity. This system, which is slow and expensive to build, is common in many countries of the eastern Mediterranean area and North

Fig. 30. INFILTRATION GALLERY BESIDE STREAM
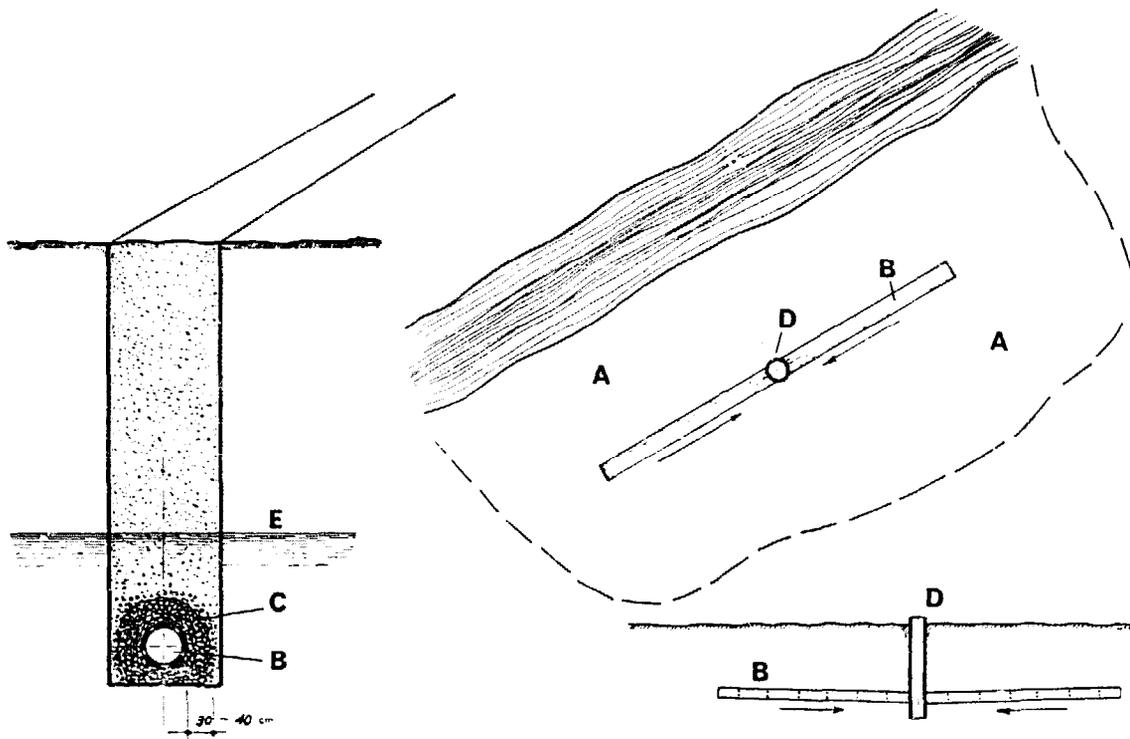
A = Sand banks beside streams offer excellent opportunities for infiltration galleries or shallow dug wells.
B = Perforated pipe should be laid on a prepared filter bed and more filter bed should be constructed over it.
C = Round, 12- to 25- mm ($^1/_2$- to 1- in.) stones should be laid around the pipe, and the filter should be built out away from the pipe with graded sand and gravel.   Filter should be 30-40 cm (12-16 in.) in thickness from pipe to extreme edge.
D = Well in middle of gallery for mounting pump and collecting water
E = Water table

Africa (e.g., " karez " or " khanat ", a gallery of a type used in Iraq and Iran), and is reported to yield substantial amounts of water for irrigation and town water-supply purposes (Fig. 31).

Improvement of Existing Wells

One of the problems that must be faced in sanitation work in rural areas is the existence of private and public wells which are open, unprotected, poorly located and constructed, and yielding unsafe water. There are both economic and social problems involved in the improvement of these wells, so that the mere spread of information to the local population that

Fig. 31. TYPE OF INFILTRATION GALLERY USED IN EASTERN MEDITERRANEAN AREA AND NORTH AFRICA
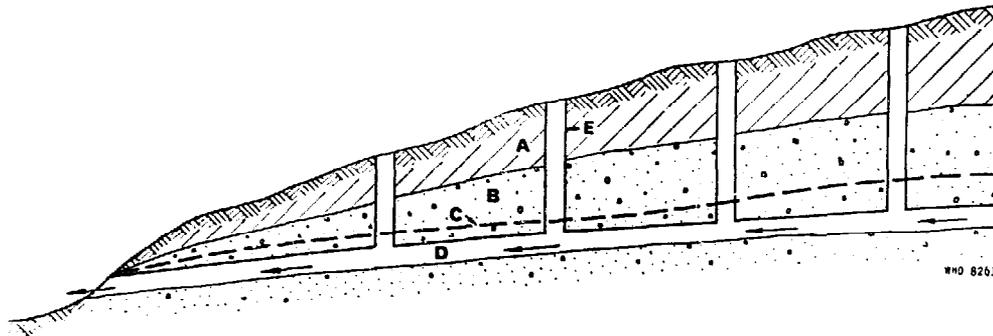
A = Ground surface (undulating country or foot of hills)
B = Water-bearing formations
C = Ground-water table
D = Small tunnel (approximately 70 × 90 cm, or 28 × 35 in.), the sides of which may be supported by rubble masonry or brick walls
E = Aeration wells

the water is unsafe is of little importance in getting improvements made. People will keep tenaciously to their habits of using a certain water source; and if it is their own well, they will insist more stubbornly than ever on using it. The health department therefore has a difficult job of education and direct assistance in improving such a situation. In these instances it should be remembered that many well-meaning public health officials have condemned and closed wells much to their sorrow, because the alternate safe source was either soon out of operation or unsuitable for some other reason. It is wise to go slowly in condemning such wells. When a better, more convenient, reliable source is available, people will go to it ; when this is not the case, no amount of condemnation will change the situation.

A scheme for improving existing wells should be a part of any sanitation programme. In almost all areas, however, the health department will have to put money into such work. It is often expensive to build wells which are properly protected and equipped from the sanitary point of view. It is best to try to recover in some way at least a part of the cost of a well-improvement programme. All kinds of financing schemes have been tried, with more or less success; but usually the only way to get an improvement is to have the people pay at least part of the cost. If they are unwilling to contribute in labour, material, or cash, any free improvement will soon degenerate to its original state. Experience has definitely demonstrated that the permanent improvement of wells is a long process involving education and direct technical and financial assistance.

Once the programme has developed to the point at which there is an interest in improving the wells, there must be a few trained people—sanitary inspectors or similar personnel—to work with families or villages and actually to supervise the work. The job is not difficult, but must be done efficiently. After the improvement is made, it must be maintained with some assistance until the habit is formed by the user or owner. This is a task that very logically falls within the realm of the inspector, and he should be trained to supervise the reconstruction as well as the maintenance.

When the sanitary inspector locates an insanitary well, his first job should be to carry out a sanitary survey of the well and its surroundings and to investigate the means for technical improvement. He should pay particular attention to :

(1)   the location of the well with respect to nearby buildings and possible sources of contamination;

(2)   the slope of the ground surface and of the water table;

(3)   the surface drainage around the well;

(4)   the condition of the platform and of the well's cover (if any);

(5)   the condition of the lining or curbing;

(6)   the method of pumping or raising water out of the well;

(7)   any other factor conducive to contamination of the ground water entering the well.

He should also ascertain the capacity of the well before deciding whether it will be necessary to deepen it in order to increase its yield. If there is considerable sediment in the bottom of the well, it should be cleaned before tests are made. Finally, the physical, chemical, and bacteriological quality of the water should be determined.

In a few instances, such as close proximity of a latrine to the well, it may be necessary to condemn the use of insanitary wells. In the great majority of cases, however, the wells may be improved and rendered safe by taking the following simple steps :

(1)   Clean out the well and deepen it to improve capacity.

(2)   Construct a casing using the best possible materials available. If a stone or brick lining already exists, it may be improved by the methods illustrated in Fig. 32, or the well may be reconstructed by using a buried slab, as shown in Fig. 15, page 79.

(3)   Build a strong and impervious platform or apron, if possible of concrete, around the well. If this cannot be done, build a tamped earth mound 30 cm (12 in.) high around the well. In both cases the platform or the mound should extend at least 1 m (3 ft) from the well in all directions.

(4)   The casing should extend at least 70 cm (28 in.) above ground.

(5)   Cover the well and install a pump or any other suitable device for drawing water from the well in a sanitary manner.

(6)   Make provision, wherever possible, for an inspection manhole.

Fig. 32. IMPROVEMENT OF EXISTING WELLS (I)
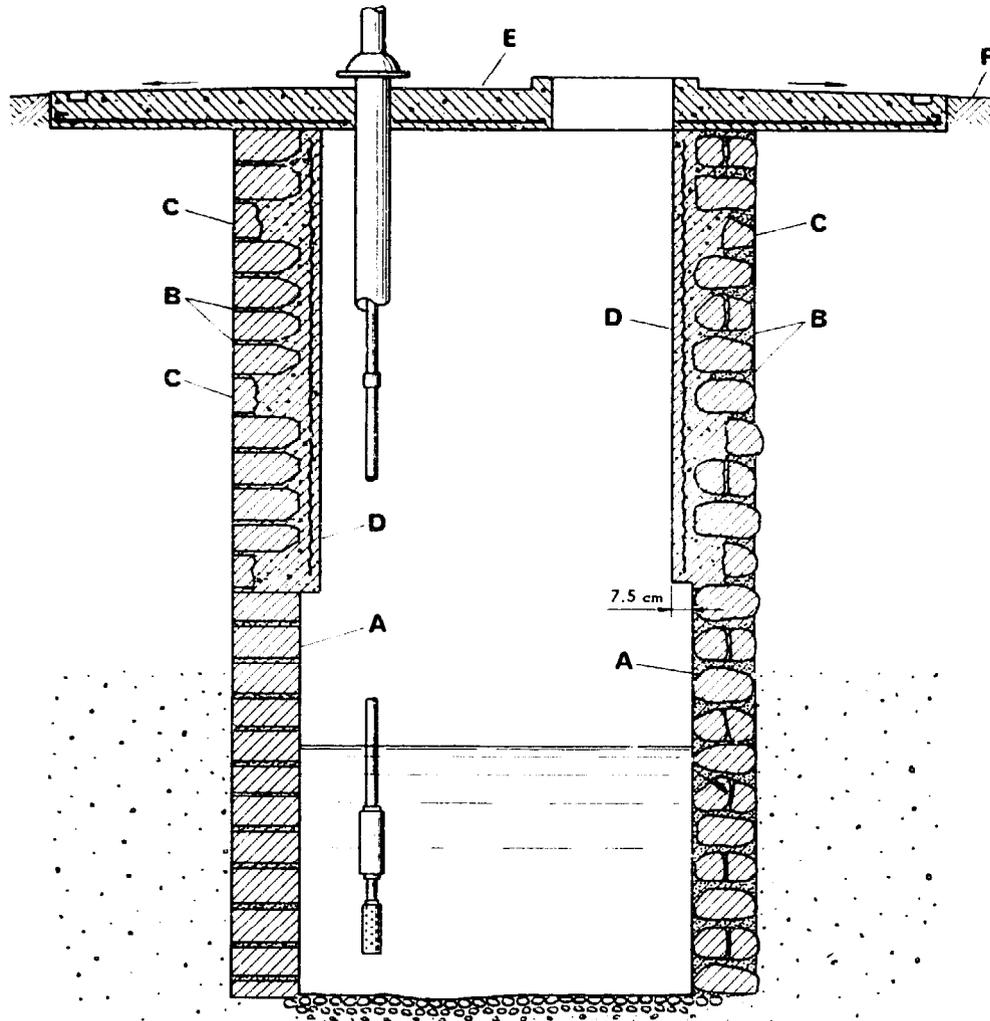
A = Existing masonry or brick walls with cracked mortar joints
B = Old mortar removed with chisel as far back as possible
C = Stone or bricks dug out to provide key for new concrete lining
D = New concrete lining, built to a depth of at least 3 m (10 ft) below outside ground level,
    or to low water level in well.   For concrete, use pea-sized gravel and wire-mesh for
    temperature reinforcement.
E = New concrete well top, incorporating sanitary features (manhole with raised edges,
    slope for proper drainage, proper pump installation, etc.).
F = Outside ground level (adequate drainage being provided for excess water or surface
    run-off)

Fig. 32 (*continued*). IMPROVEMENT OF EXISTING WELLS (II)
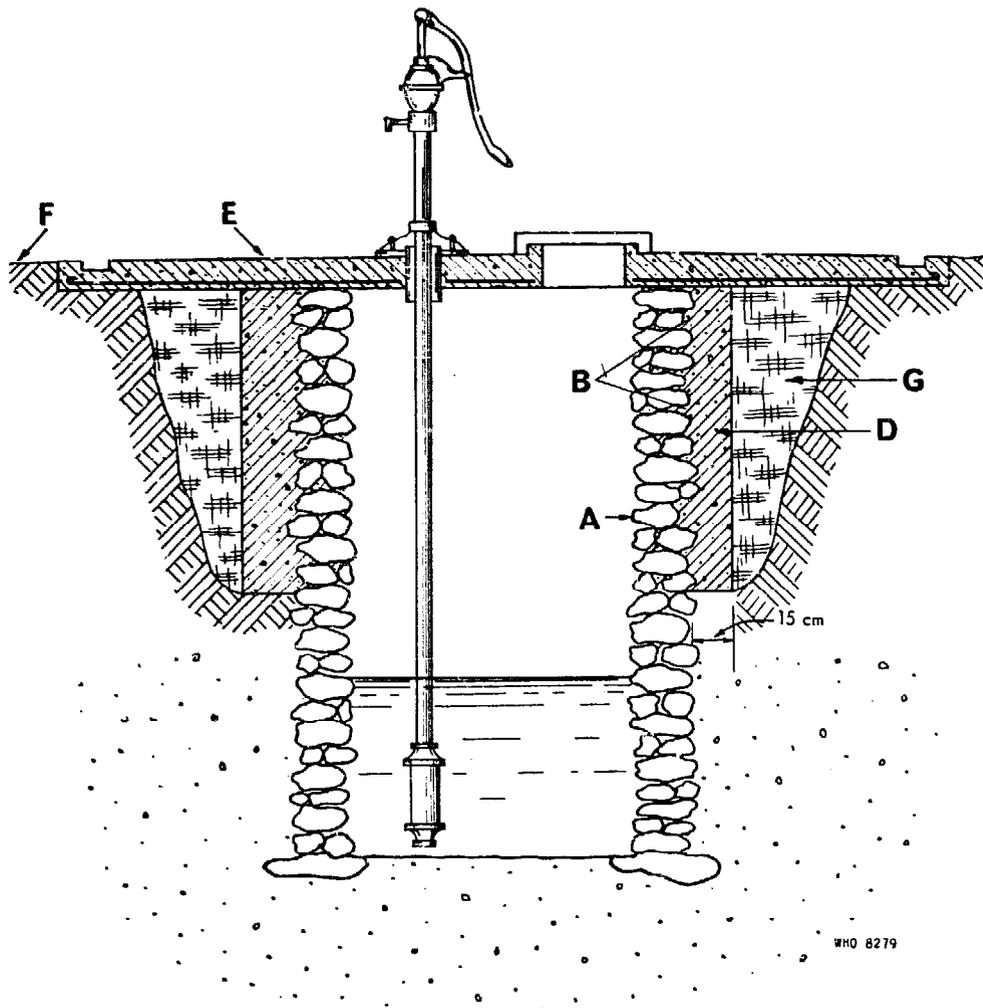
G = Backfill with clay, well tamped in layers 15 cm (6 in.) thick

Among other difficulties which may be experienced in the maintenance and operation of existing wells, the following may be cited:

(1) Depletion of the aquifer. This may be related either to drought or to overpumping, or both. In the first instance, it may be necessary to deepen the well, depending, of course, upon its actual penetration into the aquifer. In the other, it is advisable to reduce the rate of pumping until an equilibrium is reached with the amount of water which the aquifer can yield under the given set of conditions. This requires a close study of the variations in draw-down. One simple way of reducing pumping with a hand pump is to raise the suction pipe.

Fig. 32 (continued). IMPROVEMENT OF EXISTING WELLS (III)
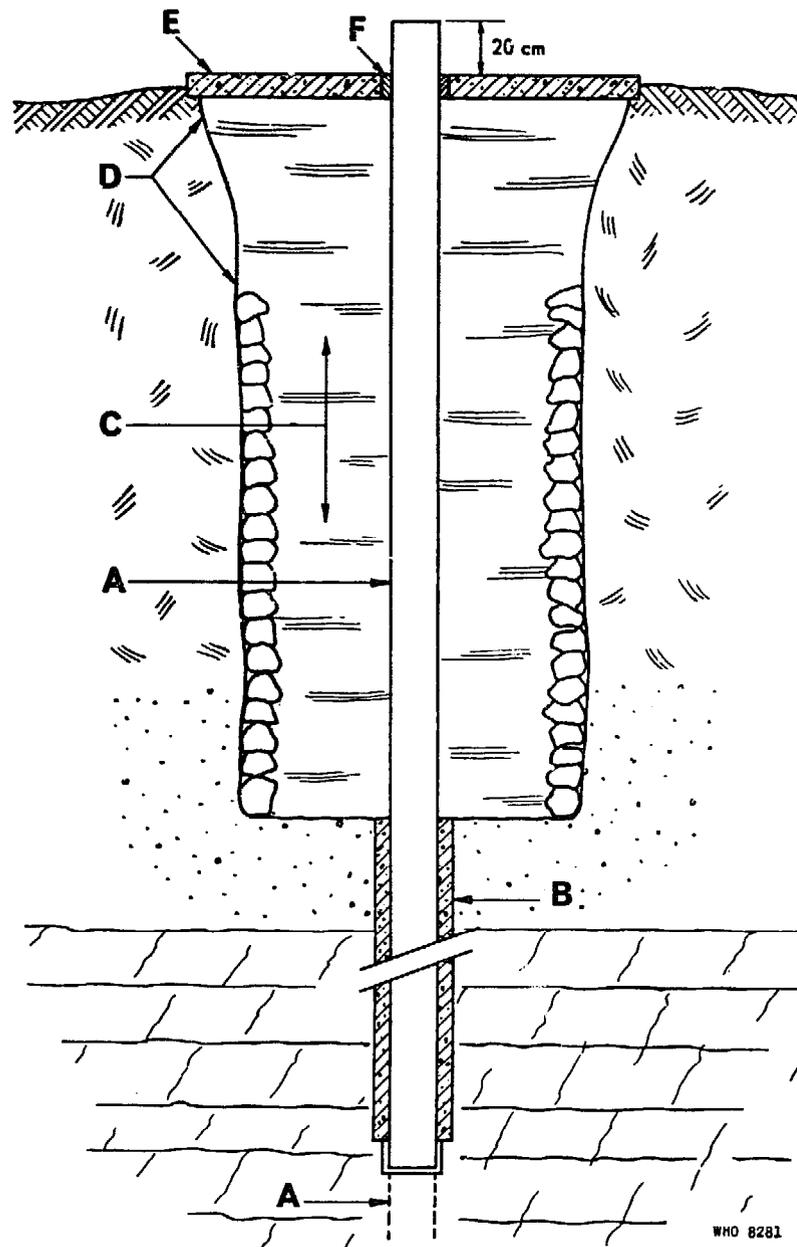
A = Drill hole and casing
B = Standard-weight casing
C = Puddled clay or equivalent
D = Curbing removed
E = New platform
F = Plastic compound

Fig. 32 (continued).   IMPROVEMENT OF EXISTING WELLS (IV)
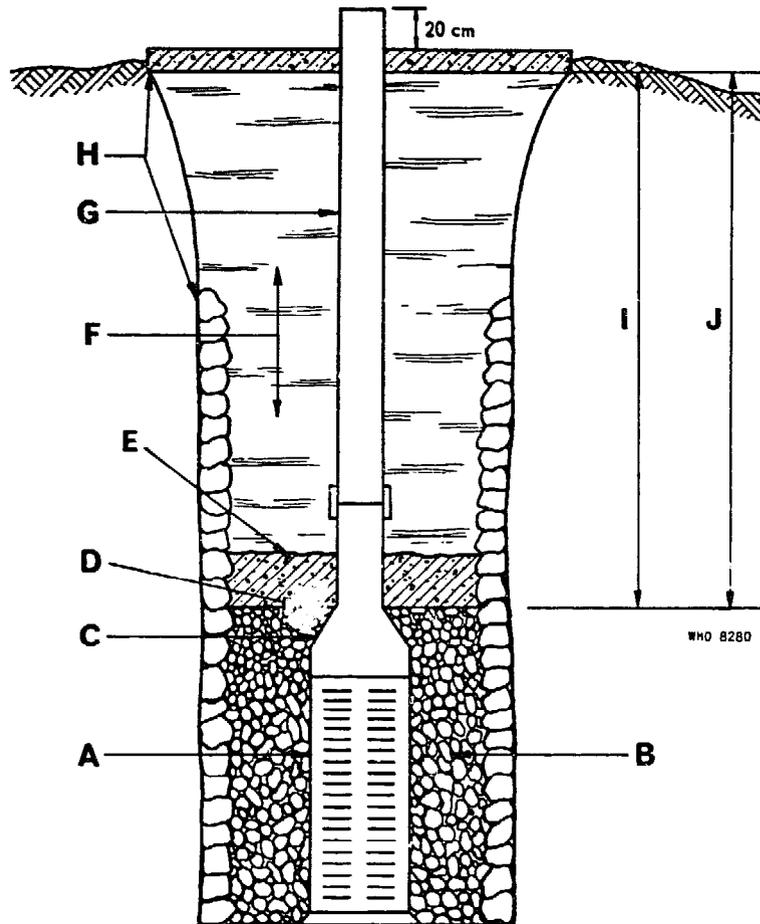

```
A = Metal or concrete screen
B = Washed, round gravel
C = Reducer
D = Metal plate
E = Poured concrete
F = Puddled clay or equivalent
G = Standard-weight casing
H = Curbing removed
I  = 3.6 m (12 ft) in clay
J  = 6.0 m (20 ft) in sand or gravel
```

The depletion of the aquifer may be due to recent construction of new wells within the circle of influence of the existing well. Such a situation will be avoided by the enforcement of strict regulations on the part of the control agency.

(2) Damage to casing or screen. This may be due to the collapse of the existing masonry or steel casing, the corrosion of the casing or screen, or the incrustation of the screen. The collapse or the corrosion of a small casing necessitates its replacement. Trouble due to incrustation can be alleviated by the introduction into the well of weak hydrochloric acid, which will dissolve the incrustant salts (most likely calcium carbonate). When a screen is obstructed by heavy growth of *Crenothrix*, the iron bacteria, a 50 p.p.m. chlorine solution will clear the difficulty. After acid treatment, the wells should be pumped before normal operation is resumed until all traces of the chemicals have disappeared.

Springs

Springs are merely outcrops of ground water and often appear as small water holes or wet spots at the foot of hills or along river banks. There are several conditions of the earth's strata capable of producing springs. Generally, springs are of the gravity or artesian type. In the first instance, the ground water flows over an impervious stratum onto the ground surface. The yield of a gravity spring will vary with the position of the water table which, in turn, fluctuates with the rainfall. Such a spring may even dry up during, or immediately after, a dry season. In the other case—the artesian spring—the water from a permeable formation or a fissure rises under pressure to the surface of the ground after confinement between two impermeable beds. The yield of an artesian spring is likely to be uniform and nearly constant over the seasons of the year.

The quantity of water from a spring can very often be substantially increased by digging out the area around the spring down to an impervious layer to remove silt, decomposed rock, and other rock fragments and mineral matter (usually calcium carbonate) sometimes deposited by the emerging ground water. In doing this, particular care should be taken, especially in fissured limestone areas, to avoid disturbing underground formations to the extent that the spring is deflected in another direction or into other fissures.

Springs in general, and gravity springs in particular, are subject to contamination in the area close to the point of emergence. A thorough sanitary survey should be conducted before development work is initiated. Such a survey should yield information on the origin of the ground water, the nature of the water-bearing strata, the quality of the water, its yield in various seasons of rainfall, the topography and vegetation of the surrounding area, and the presence of possible sources of contamination. To protect the spring, the collection structures should be so located and built as to force surface water to pass through at least 3 m (10 ft) of soil before reaching the ground water. It is also customary to exclude all animals

Fig. 33. PROPERLY PROTECTED SPRING (I)
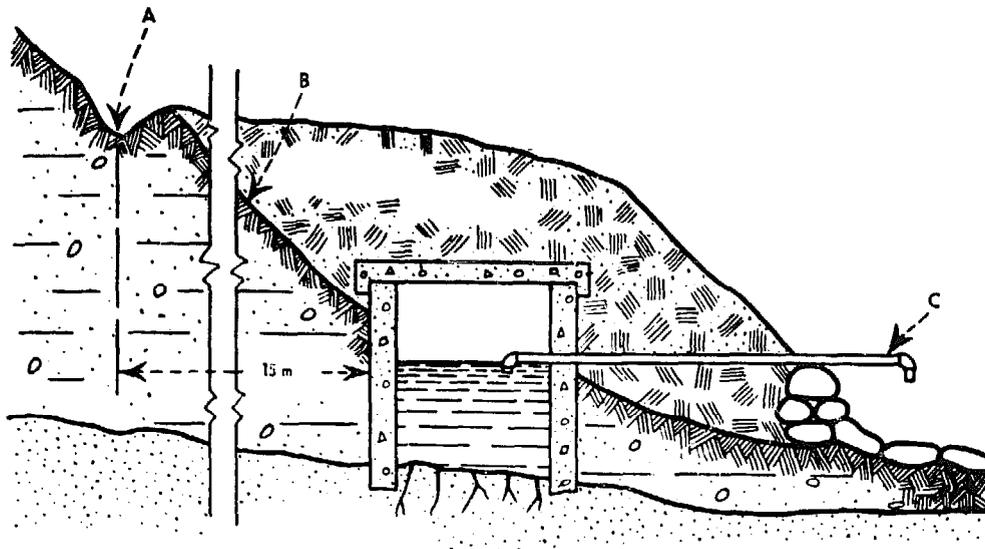
A = Protective drainage ditch to keep drainage water a safe distance from spring
B = Original slope and ground line
C = Screened outlet pipe : can discharge freely or be piped to village or residence

Springs can offer an economical and safe source of water. A thorough search should be made for signs of ground-water outcropping. Springs that can be piped to the user by gravity offer an excellent solution. Rainfall variation may influence the yield, so dry-weather flow should be checked.

Fig. 34. PROPERLY PROTECTED SPRING (II)
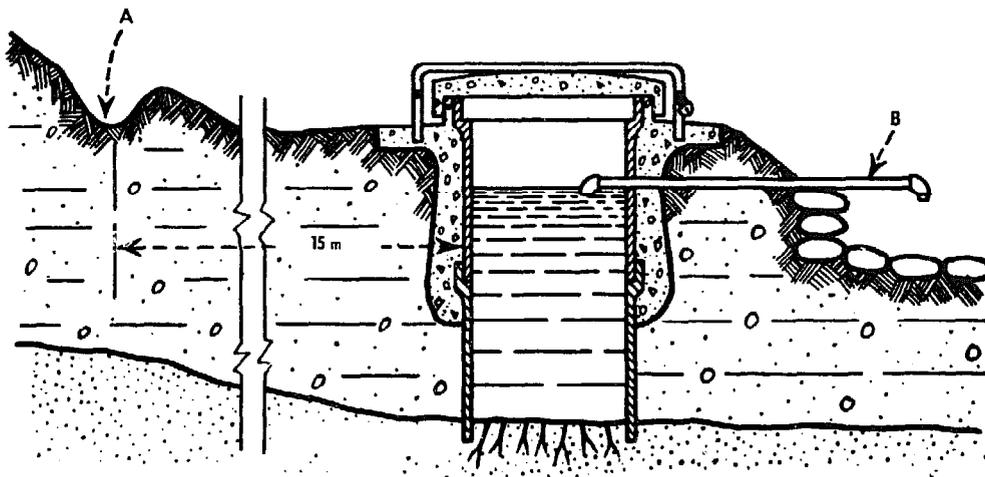
A = Protective drainage ditch to keep drainage water a safe distance from spring
B = Screened outlet pipe : to discharge freely or be piped to village or residence

8

and habitations from a substantial area (perhaps 100-300 ft, or 30-90 m) around the collection chamber, and to dig a diversion ditch above and around this to interrupt surface run-off and divert it away from the ground-water collection zone.   Springs emerging from solution channels in lime-stone formations should be carefully investigated and observed, since under such conditions very little, if any, natural filtration takes place in the ground.

Fig. 35.   TYPICAL SPRING COLLECTION-CHAMBER FOR TOWNS

A = Ground level
B = Water-bearing formation
C = Impervious stratum
D = Collection chamber
E = Openings protected by a stone-and-gravel pack in order to exclude sand and debris
F = Collecting room
G = Measuring weir
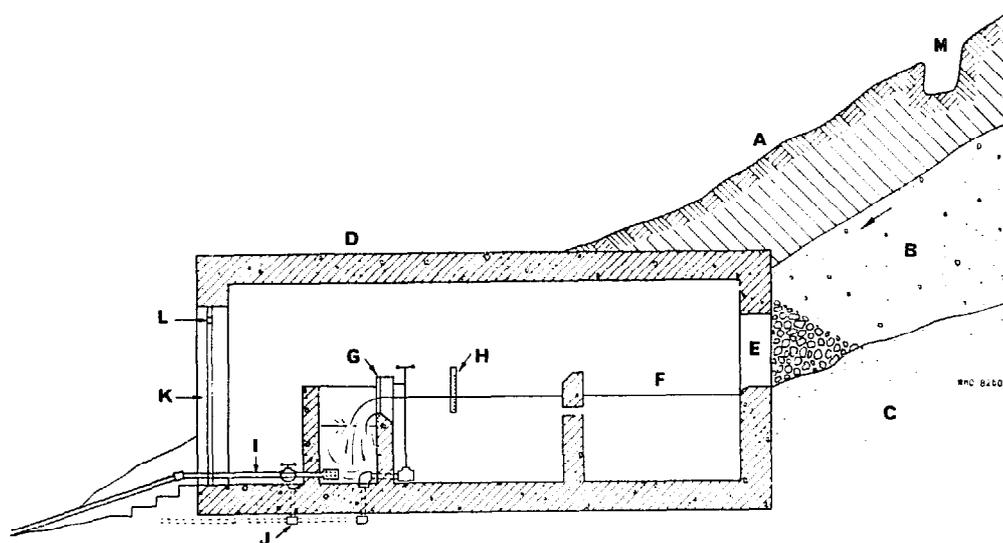
H = Measuring rod, bottom of which is level with lower edge of weir
I = Outlet pipe to reservoir or town
J = Floor drainage
K = Locked entrance door
L = Screened opening through door for ventilation purposes
M = Diversion ditch for surface run-off. Should be at least 15 m (49 ft) away from the collection structure

Such springs are likely to yield grossly polluted and turbid water soon after heavy rains, and should not be used as a source of domestic supply without a thorough study, including frequent bacteriological examination, and without the provision of corrective measures, such as filtration and/or disinfection.   Other protective measures are discussed below.

Springs, especially those which can be piped to the user by gravity, often provide an economical and safe solution to the water-supply problems of rural communities.   Fig. 33-35 show typical methods of collecting water from springs.

## Location and Protection of Ground-Water Supplies

Wells

In rural areas and villages the chances of contamination of the ground water with bacteria and chemical pollutants are often numerous. This is due to the fact that in these regions shallow ground-water is commonly tapped and used as a source of domestic supply and that this water may be reached, often without great difficulty, by pollution from privies, cesspools and seepage pits, septic tanks, and barnyard manure. It is therefore desirable to keep wells as far away as possible from likely sources of pollution.

The effects of proximity of wells to latrines and the travel of pollution through ground water have been investigated by various scientists. From their studies it appears that the travel of bacteria in the soil depends upon several factors, the most important of which are the porosity and permeability of the soil. Faecal bacteria, assisted by leaching liquids from pit privies, may be carried up to 90 cm (3 ft) horizontally. On the other hand, they may travel 3 m (10 ft) downward from pits open to heavy rains. [25] In Holland, Baars [4] found that, unless accompanied by a considerable amount of water, bacterial contamination did not travel more than 7.5 m (25 ft) through fine wet sand. Gotaas et al., [10] studying the artificial recharge of aquifers with reclaimed sewage and other waste water in the State of California, USA, found that bacteria were transported to a distance of up to 30 m (100 ft) from the recharge well in 33 hours, and that there was a rapid regression of bacterial numbers over this distance due to effective filtration and to bacterial die-off. He also found that chemical pollution travelled twice as fast. Recently, other workers, [18] studying ground-water pollution in Alaska, noted that bacteria were traced to a distance of 15 m (50 ft) from the dosing well in which test bacteria were introduced. The width of the path of bacterial travel varied between 45 cm and 120 cm (1½ ft and 4 ft). Regression then took place; and, after a year, only the dosing well remained positive for the test organism. These investigations confirm the researches made by other workers [8,9,14,15] to the effect that the contamination from excreta-disposal systems tends to travel downward until it reaches the water table, then moves along with the ground-water flow across a path which increases in width to a limited extent before gradual disappearance (see Fig. 36). These studies emphasize the primary importance of proper location of wells with respect to sources of pollution, if bacterial contamination is to be avoided.

The problem is, however, more complicated in the case of wells from which water is drawn by powerful pumps. In this case, the normal ground-water flow may be reversed within the cone of depression around the well by the draw-down, and pollution may be drawn from a source actually situated downstream from the well. After making a study of the avail-

Fig. 36. BACTERIAL AND CHEMICAL SOIL-POLLUTION PATTERNS AND MAXIMUM MIGRATIONS *
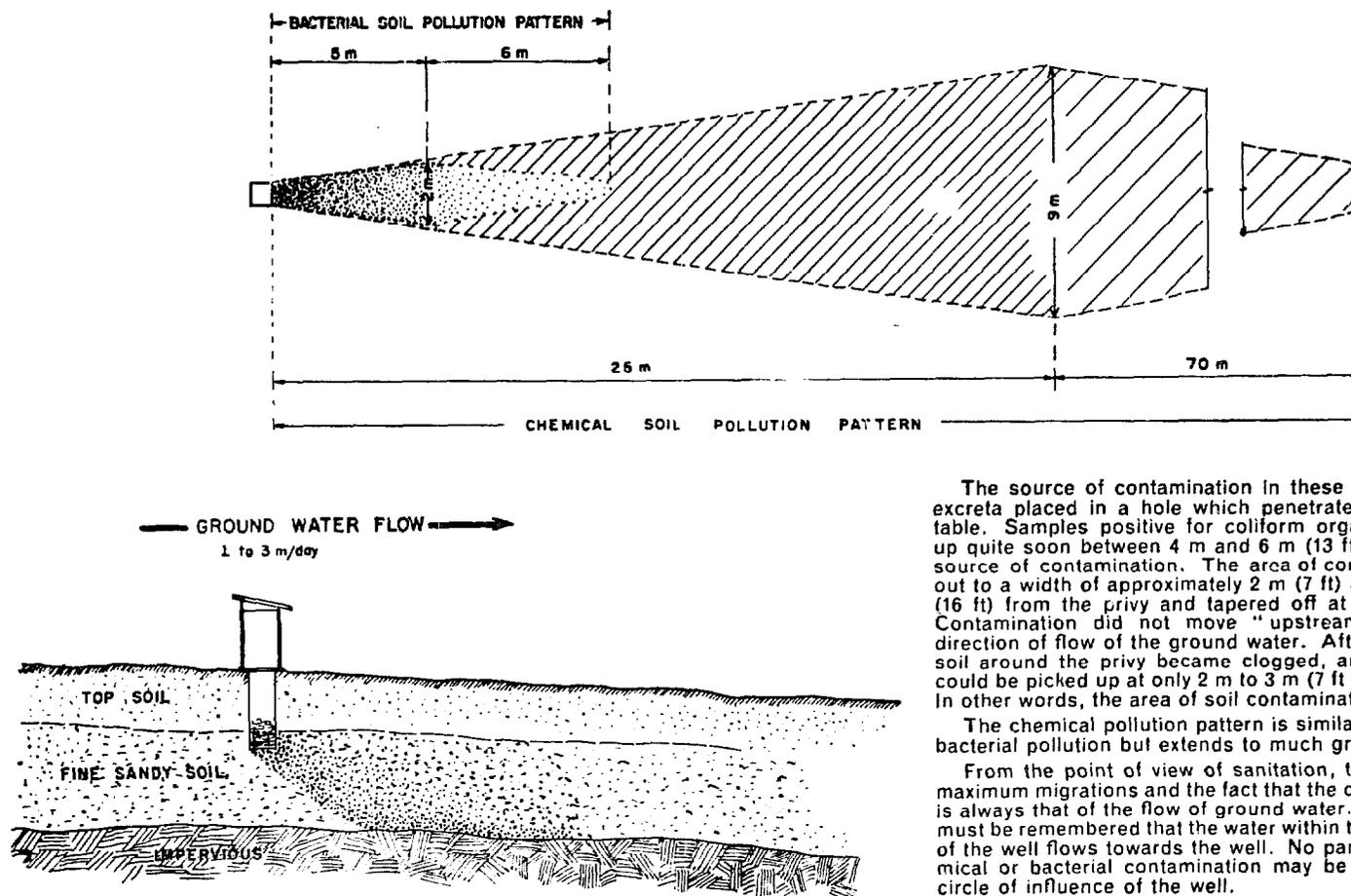
* After Caldwell & Parr [8,9] and Dyer and his fellow-workers [14,15]

The source of contamination in these studies was human excreta placed in a hole which penetrated the ground-water table. Samples positive for coliform organisms were picked up quite soon between 4 m and 6 m (13 ft and 19 ft) from the source of contamination. The area of contamination widened out to a width of approximately 2 m (7 ft) at a point about 5 m (16 ft) from the privy and tapered off at about 11 m (36 ft). Contamination did not move " upstream " or against the direction of flow of the ground water. After a few months the soil around the privy became clogged, and positive samples could be picked up at only 2 m to 3 m (7 ft to 10 ft) from the pit. In other words, the area of soil contamination had shrunk.

The chemical pollution pattern is similar in shape to that of bacterial pollution but extends to much greater distances.

From the point of view of sanitation, the interest is in the maximum migrations and the fact that the direction of migration is always that of the flow of ground water. In locating wells, it must be remembered that the water within the circle of influence of the well flows towards the well. No part of the area of chemical or bacterial contamination may be within reach of the circle of influence of the well.

able literature on the subject of soil and ground-water pollution, Wagner & Lanoix [43] stated (page 32) :

" Location of Latrines and Other Excreta Disposal Facilities

" Regarding the location of latrines with respect to sources of water supply, the following conclusions may be drawn from up-to-date information :

" 1. There can be no arbitrary rule governing the distance that is necessary for safety between a privy and a source of water supply. Many factors, such as slope and level of ground water and soil-permeability, affect the removal of bacteria in ground water. It is of the greatest importance to locate the privy or cesspool downhill, or at least on some level piece of land, and to avoid, if possible, placing it directly uphill from a well. Where uphill locations cannot be avoided, a distance of 15 m (50 ft) will prevent bacterial pollution of the well. Setting the privy off to either the right or the left would considerably lessen the possibility of contaminating the ground water reaching the well. In sandy soil a privy may be located as close as 7.5 m (25 ft) from a properly constructed household well if it is impossible to place it at a greater distance. In case of a higher-yielding well, not less than 15 m (50 ft) should separate the well from a latrine.

" 2. In homogeneous soils the chance of ground-water pollution is virtually nil if the bottom of a latrine is more than 1.5 m (5 ft) above the ground-water table. The same may be said if the bottom of a cesspool is more than 3 m (10 ft) above the level of the ground water.

" 3. A careful investigation should be made before building pit privies, bored-hole latrines, cesspools, and seepage pits in areas containing fissured rocks or limestone formations, since pollution may be carried directly through solution channels and without natural filtration to distant wells or other sources of drinking-water supplies. "

The distance of the well from the houses of users is also an important consideration. If the well is situated too far away, it will not be used and will not fulfil its real purpose : the provision of a safe water in adequate quantity for health and domestic needs. It is recommended that there should be at least one well for every 200 inhabitants in rural communities and that no user should have to carry water over a distance greater than 100 m (approximately 100 yards). Yet, precaution must be taken to avoid placing a well too close to barns, manure piles, etc., from which excessive chemical pollution in the form of nitrates may be obtained. A high nitrate content in drinking-water is known to produce methemoglobinaemia in infants. [7]

Other sanitary measures which should be taken in order to exclude the entry of surface water are the following :

(1) The ground surface in the immediate vicinity of the well should slope away from it and should be well drained.

(2) In the case of public wells, a special drainage system should be provided for waste water.

(3) The pump platform or well cover should be at least 60 cm (2 ft) above the highest level of floods from nearby rivers, and should be well protected against flood waters and surface run-off generally. It should be watertight, preferably of concrete 10 cm (4 in.) thick, and may extend about 60 cm (2 ft) beyond the well lining. Its surface should slope from the centre

towards a drain built along its edges (see Fig. 33, page 113).   The waste water should then be collected by a lined ditch leading to a suitable drainage area or soakage pit, in order to avoid the occurrence of muddy ground and bogs in the immediate vicinity of the well.

(4)   In the case of driven, jetted, and drilled wells, an annular space at least 4 cm (1½ in.) wide on the outside of the well casing may be grouted with cement in order to prevent surface water from reaching the casing   l running down along it to the ground water.   The cement grout mix   e will consist of one bag of cement (94 lb. or 42.7 kg) and 19-21 litre 5- 5½ US gal.) of clean water to which hydrated lime is added to the   nt of 10% of the cement volume.   The depth of the seal should be   st 3 m (10 ft) below ground surface.

(5)   When manholes are provided for dug wells, the rims sh   ro- ject at least 8 cm (3 in.) over the surrounding surface, and   manhole cover should overlap the rim as shown in Fig. 13 (see page ⁻⁻

One more factor involved in the location of wells when   re than one well must be built and pumped simultaneously is the need to avoid an undue amount of interference between them.   For this reason, wells should not be too close to each other and, when penetrating the same aquifer, they should be located on a line transverse to the direction of ground-water flow.   Usually spacings for deep wells vary from 150 m to 300 m (500 ft to 1000 ft) or more.   The effect of interference upon the flow of water in closely grouped wells has been studied by Muskat.[28]

Before being put into operation, or immediately after repairs, a well should be disi fected to neutralize the bacterial contamination which may have been introduced by workmen, equipment, or surface water during construction.   First, the casing or lining should be washed and scrubbed with a strong solution containing 100 p.p.m. of available chlorine.   Such a solution is obtained by dissolving 50 g (1¾ oz.) of chlorinated lime in 100 litres (26 US gal.) of water.   Then the volume of water in the well is measured and a chlorine solution is added in such a manner that the effective chlorine dose is between 50 p.p.m. and 100 p.p.m.   The solution should be applied at different levels in the well water, which should be agitated to ensure even distribution.   The chlorinated water is allowed to stand for at least 12 hours, after which it is pumped out.

As a measure of protection of ground water, abandoned wells should be permanently sealed with puddled clay after as much as possible of the existing lining has been removed.   This measure is necessary in order to ensure the protection of nearby domestic wells.

Infiltration galleries

The same general rules given above are applicable to infiltration galleries. These structures should be located away from all possible sources of pol-

lution. Diversion ditches should be built around the galleries in order to prevent surface water from running directly over them and from entering without adequate natural filtration.

Springs

Most of what has been said above applies also to the location and protection of springs. The principle remains the same, i.e., the prevention of outside contamination from entering either the collection chamber or the ground water in the vicinity of the chamber. The following may be added:

(1) The collection installation should be so built as to exclude light and, in this way, to prevent the growth of algae.

(2) The overflow pipe should be so located as to prevent the entrance of surface water at times of heavy rainfall.

(3) Manhole covers and gates should be kept locked.

(4) Before the collection chamber is put into operation, the inside wall surface should be disinfected in the same manner as described for wells (see page 118).

Testing of Wells for Draw-down and Yield

After a well is completed, it is often desired to determine its yield, i.e., the amount of water which can be steadily withdrawn by pumping when the draw-down has reached an equilibrium and remains constant. The pumping tests should not be made immediately upon completion of the well but rather after several weeks, and preferably after one month, of normal daily operation of the pump. The yield of a new well tested soon after completion is invariably

Fig. 37. SET-UP FOR DETERMINING DRAW-DOWN
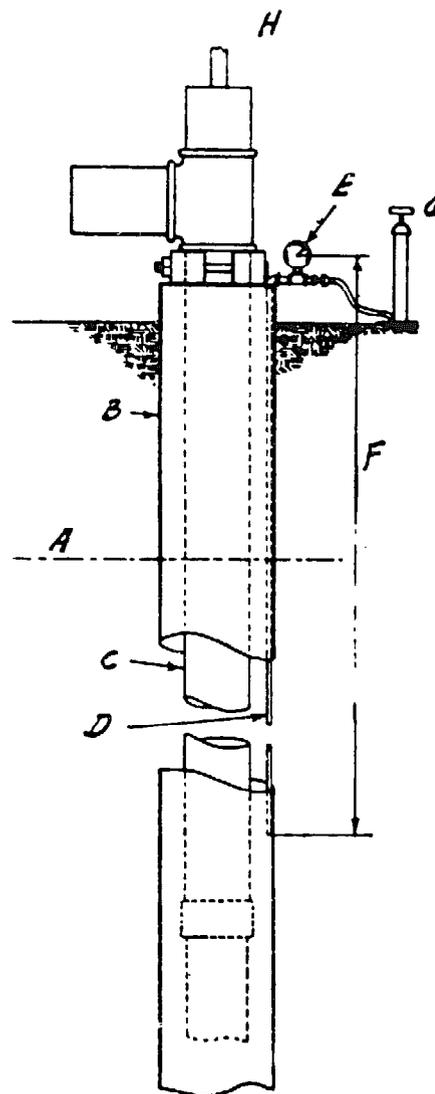
A = Static water level
B = Well casing
C = Pumping pipe
D = Air pipe
E = Pressure gauge
F = Total vertical length of air pipe
G = Bicycle or tire pump
H = Shaft of motor pump

10% to 30% greater than the yield at the same rate of pumping a month later.[6]

When these tests are made, it is necessary to take frequent measurements of the draw-down, i.e., the distance between the static water level and the pumping level in the well. A convenient method of measuring the depth of water in small well-installations involves the use of an air-line or tube and a manometer installed as shown in Fig. 37. When air is pumped into the tube, the reading on the manometer increases until the water in the tube has been expelled. At this point the manometer will indicate the amount of pressure required to balance the depth of water outside and above the lower end of the air-line in the casing. This pressure is converted into metres of water and is subtracted from the vertical distance between the manometer and the end of the air-line. The figure obtained is the depth of water in the well. By repeating this measurement during pumping operations, it is possible to determine the depths of water and the draw-down levels for each rate of pumping. The corresponding pump discharges will be determined by means of a weir or an orifice. These methods are described in Annex 3 (page 260). With the data obtained, it is then possible to establish a capacity curve for the well under consideration.

Chapter 4

PUMPS

In rural areas some villages may be so situated as to obtain their water supplies entirely by gravity from springs or infiltration galleries originating in nearby hills. Other villages and individual farms may depend on pumps to raise water from wells, lakes, or reservoirs, or to boost water into distribution pipes. The choice of the right pump for any particular situation is of the utmost importance. Experience shows that pumping problems are most often responsible for the breakdown or poor operation of small water-supply systems. It is therefore appropriate to include in this monograph a brief discussion of various types of pumps, their principles of operation, and their efficiency and maintenance. It is important to remember that each pump has been developed by its manufacturer for a specific purpose, and has a definite range of application. It is the responsibility of the water-supply designer to choose the pump that will do the best job at the least cost.

The most common types of pumps for small-community water systems, individual houses, or public wells are :

(1) hand- or power-operated reciprocating pumps, where the cylinder is above ground as part of the pump's body;

(2) power-operated centrifugal pumps with the pump mechanism above ground;

(3) hand-, power- or wind-operated reciprocating deep-well pumps, where the cylinder is in the well;

(4) deep-well turbine pumps driven either from the surface or from a submersible electric motor;

(5) jet pumps, power-driven at the surface; and

(6) hydraulic rams.

A further type, rarely used for water production but very useful for testing purposes, is the air-lift pump, operated by a power-driven compressor on the surface.

Under ideal conditions the pressure of the air at sea level is enough to raise a column of water 10.3 m (34 ft) in a vertical pipe in which a perfect vacuum has been made. Conditions under which pumping usually takes place are far from ideal (because of pump imperfections, air leaks, the

TABLE VI. RELATIVE MERITS OF PUMPS FOR USE IN SMALL WATER-SUPPLY SYSTEMS

Types of pumps	Positive displacement			Velocity			
	hand pumps, plunger type	motor, wind driven, plunger type	chain or continuous bucket	centrifugal	deep-well turbine	jet	air-lift
Efficiency range (%)	Low; can be improved with double-acting cylinders: 25%-60%	Low; can be improved with double-acting cylinders: 25%-60%	Low	Good: 50%-85%	Good: 65%-80%	Low: 40%-60%	Low: 25%-60%
Operation	Very simple	Simple	Very simple	Simple	More difficult; needs attention	Simple; air locks can cause trouble	More difficult; compressor needs attention
Maintenance	Simple, but valves and plunger require attention; more difficult when pump cylinder is in the well	Same as hand pump; maintenance of motors sometimes difficult in rural areas	Simple	Simple, but attention is necessary	More difficult and constant; skilled attention is necessary	Simple, but attention is necessary	Compressor needs constant attention
Capacity (litres/minute)	10-50	40-100	15-70	Very wide range: 5 to unlimited	Very wide range: 100-20 000	25-500	25-10 000

Head (metres)	Low	High	Low	5-500	20-500	Low	Low
Cost	Low, but higher when cylinder is in the well	Low, but higher when cylinder is in the well	Reasonable	Reasonable	Higher, especially in deep wells	Reasonable	Reasonable
Advantages	Low speed; easily understood by unskilled people; low cost	Low cost; simple; low speed	Simple; easy to operate and maintain	Efficient; wide range of capacity and head	Good for small-diameter boreholes; ease of operation	Moving parts on surface; ease of operation	Moving parts on surface; can pump turbid and sandy water
Disadvantages	Low efficiency; limited use; maintenance more difficult when cylinder is in the well	Low efficiency; limited use; maintenance more difficult when cylinder is in the well	Low efficiency; limited use	Moving parts and packing require attention	Moving parts in well; rather expensive; requires good maintenance and operation	Limited application; low efficiency; moving parts require attention	Limited application; low efficiency; compressor requires constant attention
Power	Hand or animal	Wind, motor	Hand, animal, wind, motor	Motor	Motor	Motor	Motor

presence of air in water, etc.).   In practice, the suction lift, i.e., the vertical distance from the pump cylinder to the water surface, should never be more than 5-6 m (16-20 ft).   Pumps installed in this way need to be primed before they can operate; that is, the suction pipe must be filled with water from an outside source in order to eliminate air; and this priming water can in itself carry severe risk of pollution unless strict precautions are observed.

When the suction lift would be greater than 5-6 m (16-20 ft), the pump cylinder should be lowered into the well, or some other type of pump must be used-for instance, one in which the pumping action takes place within 5-6 m (16-20 ft) of the surface of the water (i.e., within the distance of possible suction lift).   Another method consists of immersing the pump cylinder, jet, or turbines in the well water.   This method has the further advantage of avoiding the need for priming the pump.

Classification

There seems to be an infinite number of classifications for pumps.   The one chosen here is based on the mechanical principles involved.

   (1)   Displacement
      (a)   reciprocating
      (b)   rotary
      (c)   chain
   (2)   Velocity
      (a)   centrifugal (standard centrifugal and deep-well turbine)
      (b)   jet
   (3)   Buoyancy : i.e., airlift
   (4)   Impulse : i.e., hydraulic ram

Table VI shows some of the relative merits of these various types of pumps.   In the following paragraphs the practical characteristics of those pumps most commonly used under rural conditions are discussed.

Types of Pumps

Displacement pumps

By far the largest category of pumps under this heading is the reciprocating plunger pump in which water is moved by the direct push of a plunger, piston, or bucket which reciprocates in a closed horizontal or vertical cylinder.   By an arrangement of valves this reciprocating motion of the plunger produces a more or less steady stream of water flowing in one direction : in the simplest type, the plunger on the forward stroke pushes the water from the cylinder up a discharge pipe, while at the same time the space behind the plunger is filling from the suction pipe; the reverse stroke

Fig. 38. ELEMENTARY, SINGLE-ACTING, FORCE PUMP SHOWING DISTINGUISHING FEATURE OF CLOSED CYLINDER
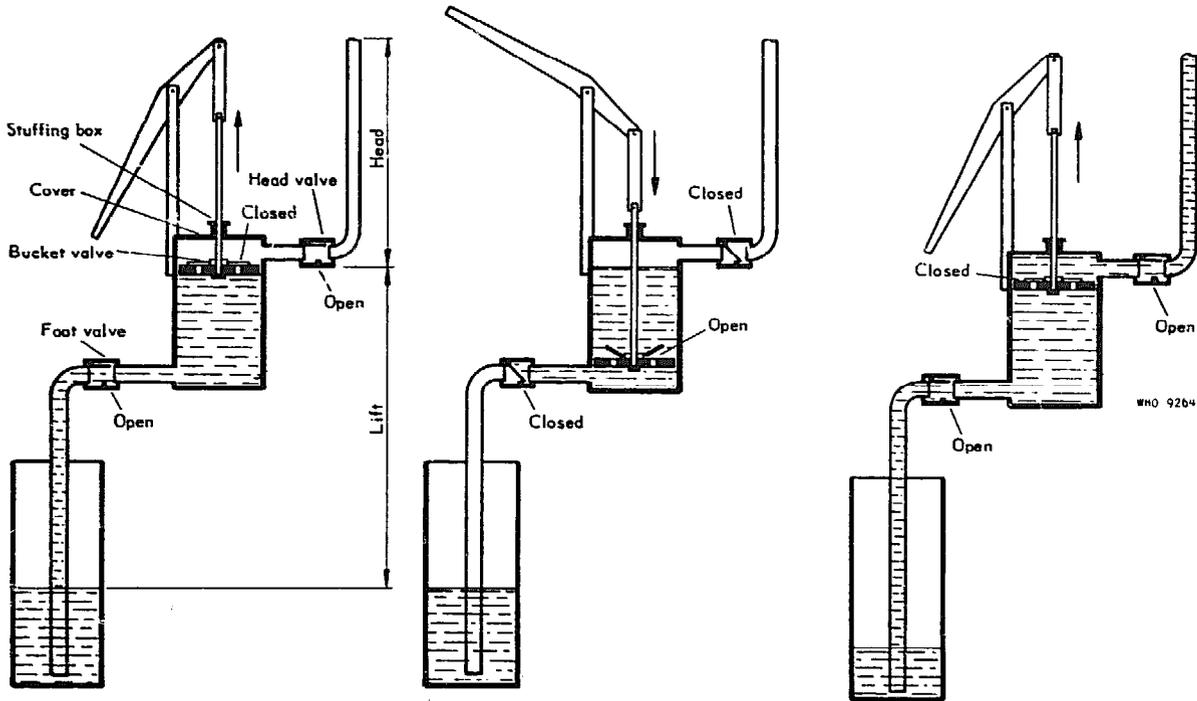
Adapted by kind permission from Graham, F. D. & Emery, T. J. (1942) *Audel's Plumbers' and steam fitters' guide*, No 1, New York, p. 2748.

In addition to the foot and bucket valves of the lift pump, a head valve is provided.

In operation, during the up-stroke, atmospheric pressure forces water into the cylinder; during the down-stroke, this water is transferred from the lower to the upper side of the piston.

transfers the water from the suction to the forward side of the plunger (see Fig. 38).

Other minor categories under this heading include the semi-rotary hand pump, chain and bucket pumps, and any other device of bucket and windlass or bucket and counterweight where water is moved by the direct push of a moving container or impeller.

The *reciprocating plunger pump* is probably the most widely used throughout the world since it ranges from small, hand-operated plungers of a centimetre or two in diameter to huge, steam-driven pistons whose diameters may equal a metre or more. Very large pumps of this class are rarely installed today, since the centrifugal type has many advantages in the larger ranges; but for rural water-supplies in sizes up to, say, 15 cm (6 in.) in diameter, the reciprocating pump is extensively used in power-driven installations, and almost exclusively so in wind-, animal-, or hand-operated units.

Some of the main advantages of this type of pump in power-operated schemes are as follows :

(1) *Flexibility* : The delivery from a plunger pump is the volume of water displaced in the cylinder times the number of strokes of the plunger in a given time. Within wide limits the speed of the plunger can be varied, and the delivery varies in exact proportion. Only when too rapid a motion of the piston causes " slip ", or movement of water backwards between the plunger and cylinder walls, is the limit of capacity reached. In addition, in most types performance can be adjusted by varying the length of stroke. Consequently, a pump of this type has a wide range of duty with little decrease in efficiency—i.e., the efficiency curve is a very flat one (see below)—and it is possible to standardize on a particular type of pump to meet varying conditions, thus reducing the number and type of spares and replacements to be carried. Another advantage accruing from this flexibility is the ability of an individual pump to perform varying duties without loss of efficiency. An instance of this is in a scheme where the reservoir is designed as a balancing tank " floating " over the distribution system. At peak hours when large draw-offs take place on the rising main, the head on the pump may be low; at other times, when the whole of the water is being delivered to the reservoir, the pump will work against a high head. A reciprocating pump is better able to carry out these different duties than other types.

(2) *Speed of operation* : This type of pump normally needs a slower prime mover than a centrifugal type; consequently, wear is reduced and the life of both the pump and the engine is prolonged. Small variations in speed cause only small variations in output, so that less accuracy is required in adjustment.

(3) *Ease of maintenance* : With slow-moving bucket pumps little maintenance is required other than replacement of the leather bucket or plunger washers, and these are relatively easy to fix. The wear on these leathers is dependent on the purity of the water pumped : if it is free from silt or abrasive matter they may last for years without replacement. Properly used, these pumps rarely require any expensive replacements; and any work done on them can be carried out by relatively unskilled staff.

(4) *Robustness* : There are few, if any, delicate parts in this type of pump; and it will stand mishandling better than centrifugal pumps, where dimensions may be critical. Should the water fail, for instance, and the plunger continue to operate without actually pumping, little damage will be done; a similar situation in a high-speed turbine pump would quickly ruin the whole mechanism.

(5) *Initial cost* : Because of their simplicity, the cost of reciprocating pumps is usually lower than that of centrifugal pumps of similar capacity.

The hand-operated pump (Fig. 39, 40, and 41A) can be used in wells of any depth. In those which have a draw-down level of less than 5 m (16 ft), the cylinder is usually placed above ground. When the static water

Fig. 39. DISPLACEMENT PUMP OPERATION

A
B   WHO 9255
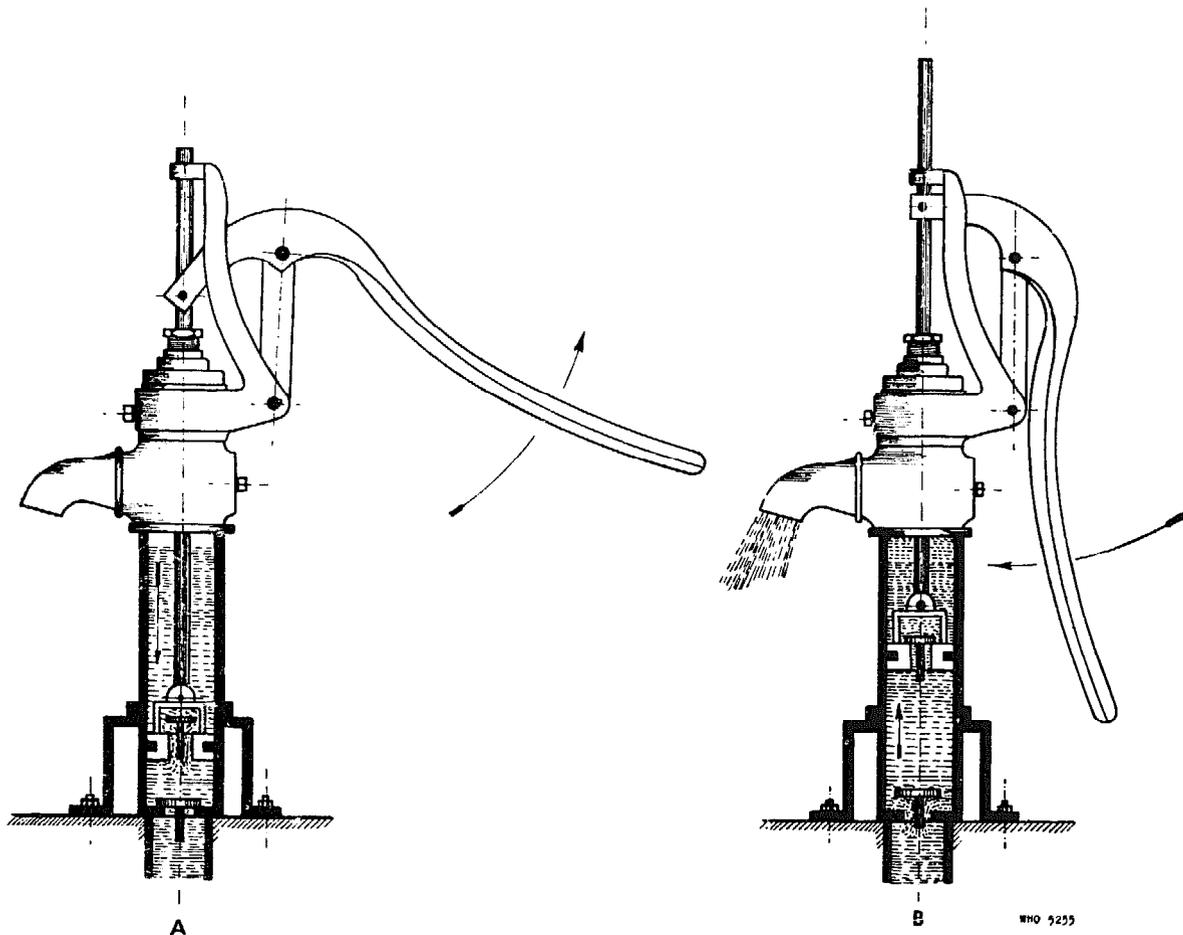
A = Down-stroke: Cylinder above plunger fills while valve at base of cylinder closes, and valve in plunger opens.

B = Upstroke: Cylinder full of water above plunger is expelled while, at the same time, valve at base of pump opens, filling cylinder below plunger.   As plunger rises, a vacuum is formed below, pulling water into the cylinder.

When the cylinder is above ground, a foot valve is necessary to avoid pumping.

level is more than 5 m (16 ft) the cylinder is attached to a drop-pipe and placed in the well as shown in Fig. 13-15 (see pages 77-79).

This type of pump is quite reasonable in cost, especially the reciprocating pump of which the cylinder is above ground. It can give good service provided the plunger leathers and cylinder valves (Fig. 41) are maintained. The maintenance process is simple but must be carried out repeatedly. Where a closed cylinder (Fig. 41) is placed in the well, some complication is introduced because, in order to maintain the installation, the cylinder and

Fig. 40. HAND-PUMP FLEXIBILITY IN USE
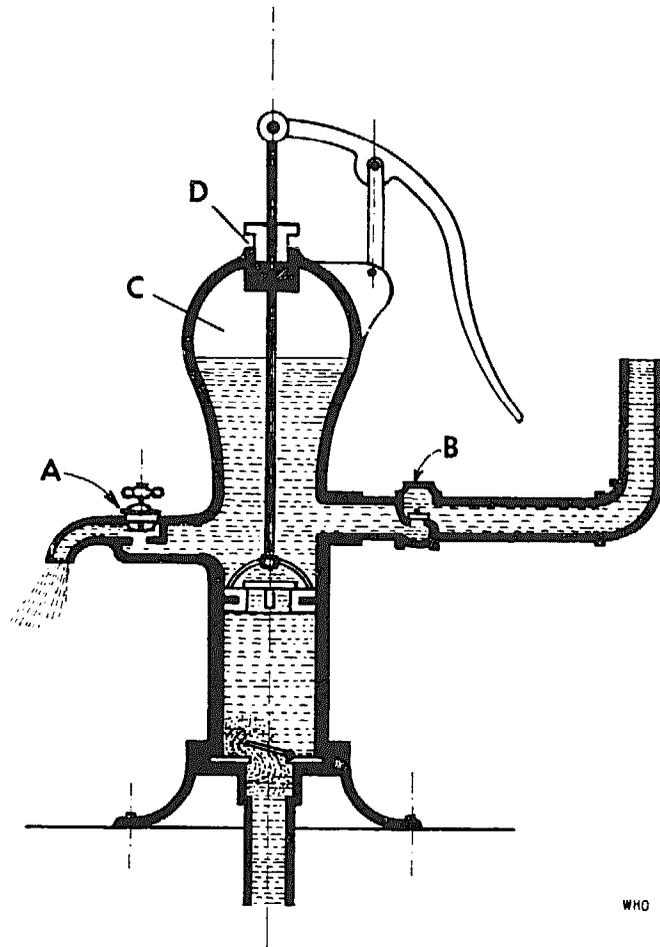
WHO 5258

A = Hand-operated valve
B = Check valve
C = Air chamber
D = Stuffing box

With this arrangement, water can be taken out at the pump or pumped up to a point at a higher elevation by closing valve A.

drop-pipe must be removed.   Open-end cylinders are available which are built in such a way that the bucket and foot valves, together with the pump rods, can be removed to the surface without taking out the drop-pipe.   In any case, under rural conditions such pumps are much more difficult to maintain than other pumps whose cylinders are above ground.

Priming is usually necessary for pumps with cylinders above ground where suction is required in order to get the water up to the plunger, since the cylinders, leathers and valves wear with time, causing a leakage of air

Fig. 41. PUMP CYLINDERS AND PUMP CYLINDER VALVES
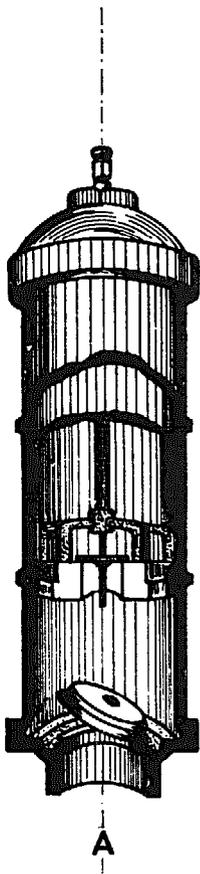
A = Closed-type cylinder
B = Open-type cylinder with ball valve. Plunger may be removed without taking cylinder from the well.
C = Poppet valve
D = Spool valve
E = Spring-activated poppet valve
Leathers and valves wear on all types of cylinders and need replacement from time to time.

WHO 5270

A B

WHO 5271

C D E

9
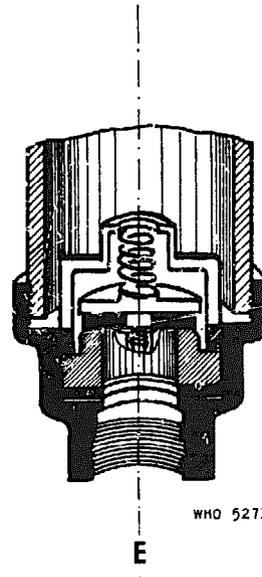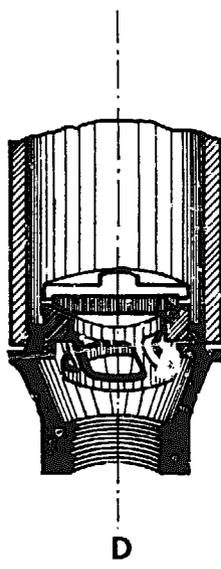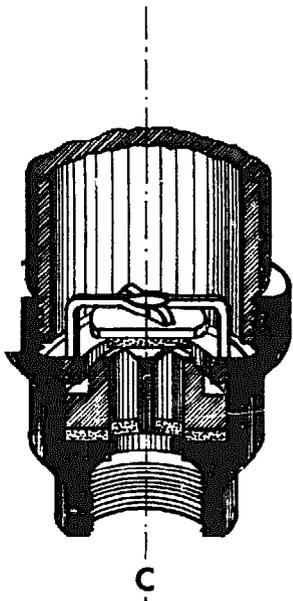
into the suction line.   As a result, the vacuum beneath the plunger is broken and, in order to pump again after a short interval of time, water must be put into the cylinder from above.   When the pump is delivering into a rising main, this priming can be effected by allowing the water in this rising main to flow back into the cylinder through a simple bypass; but, when the pump discharges directly into the open air (as in Fig. 39, 40), a quantity of priming water must be introduced from an external source.   This process obviously offers a good chance for the introduction of contamination into the well; in fact, this is almost inevitable.   Therefore, from the sanitary point of view, pumps whose cylinders are immersed in the well water below the point of maximum draw-down have definite advantages.

Hand-operated reciprocating pumps have a capacity limited by the power which can be exerted by one or two men.   Consequently, the lower the level from which the water must be drawn, the less the amount delivered.   Some typical figures are as follows :

Shallow pump, operated by one man, lift 6 m (20 ft), 35 litres (9 US gal.) per minute

Deep-well pump, operated by one man, lift 30 m (100 ft), 6 litres (1½ US gal.) per minute

Deep-well pump with rotary head, operated by two men, lift 30 m (100 ft) 15 litres (4 US gal.) per minute.

With hand-operated pumps, an air chamber is sometimes incorporated (as in Fig. 40) to give a smooth flow and increase efficiency when pumping through a rising main; with power-operated pumps, such air vessels are invariably installed, and occasionally differential plungers are also used for this purpose.

Reciprocating pumps on the surface operated by electric, diesel, or petrol motors (Fig. 41A) can have a total capacity limited only by the size of the power unit; but the length of the suction is limited as described on page 124.   They can also be designed to pump to considerable heads above pump level.   When they are operated below ground, however, a limiting factor is the diameter of the cylinder which can enter the bore-hole casing. For single-acting pumps, the following are some typical delivery capacities, using a 12 h.p. prime mover :

9.5-cm (3¾-in.) barrel, for 10-cm (4-in.) rising main to go into a 15-cm-(6-in.-) diameter bore-hole } gives { 100 litres (26 US gal.) per minute against 131 m (430 in.) total head

14.6-cm (5¾-in.) barrel, for 15-cm (6-in.) rising main to go into a 20-cm-(8-in.-) diameter bore-hole } gives { 250 litres (66 US gal.) per minute against 56 m (185 in.) total head

In order to increase the efficiency of a single-acting barrel (i.e., one in which water is lifted on the upward stroke only), counterweights are usually

fitted to keep the engine running with even power; but double-acting cylinders can also be fitted (Fig. 42). The latter obviate the use of counter-weights and give increased output; but they are more susceptible to maintenance troubles, particularly when there is any sand in the water pumped.

Fig. 42. DOUBLE-ACTING DISPLACEMENT PUMP
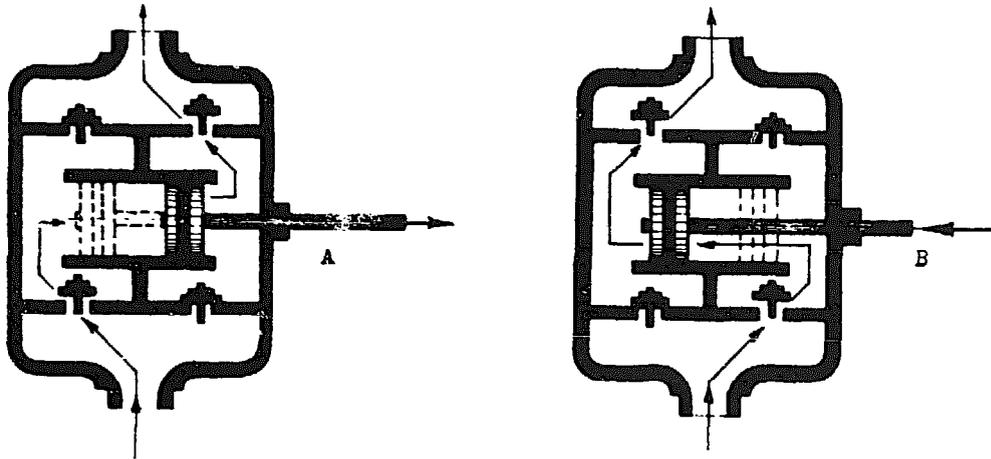
When piston is in position A, intake is at lower left and discharge at upper right. In position B, intake is at lower right and discharge at upper left.

Fig. 43. TYPICAL SEMI-ROTARY HAND PUMP

Inside view   Front view
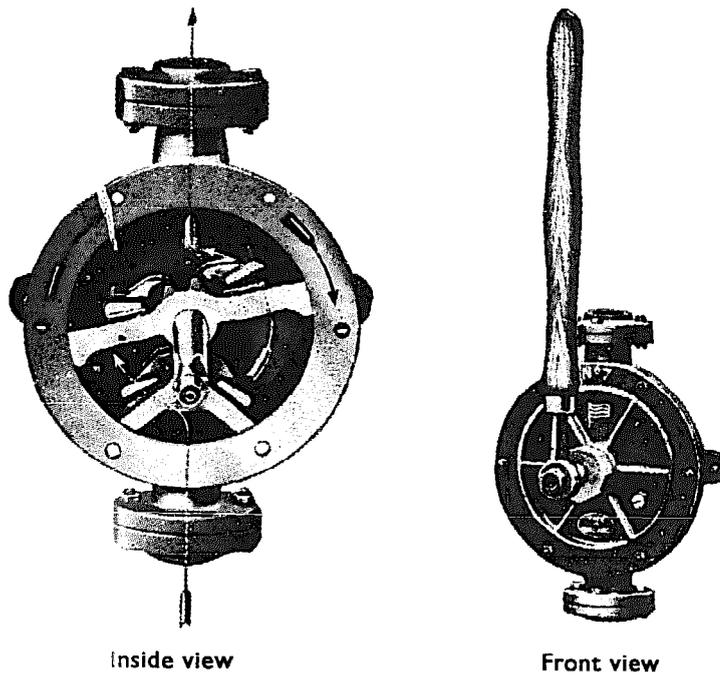
Reproduced by kind permission of Lee, Howl & Co. Ltd. (Catalog A, 1955, pp. 34, 37), Tipton, Staffs., England.

They are also more expensive and more difficult to repair.   Typical delivery capacities of double-acting cylinders are :

|		
8.3-cm (3¼-in.) barrel, for 10-cm (4-in.) rising main to go into 15-cm- (6-in.-) diameter bore-hole	gives	185 litres (49 US gal.) per minute against 198 m (650 in.) total head
13.3-cm (5¼-in.) barrel, for 15-cm (6-in.) rising main to go into 20-cm- (8-in.-) diameter bore-hole	gives	370 litres (98 US gal.) per minute against 91 m (300 in.) total head.

Hand-operated plunger pumps of varying types are popular in most areas where small outputs are required.   In some places attempts have been made, with varying degrees of success, to build such pumps out of

Fig. 44.   A SANITARY ROPE-AND-BUCKET WELL (I)
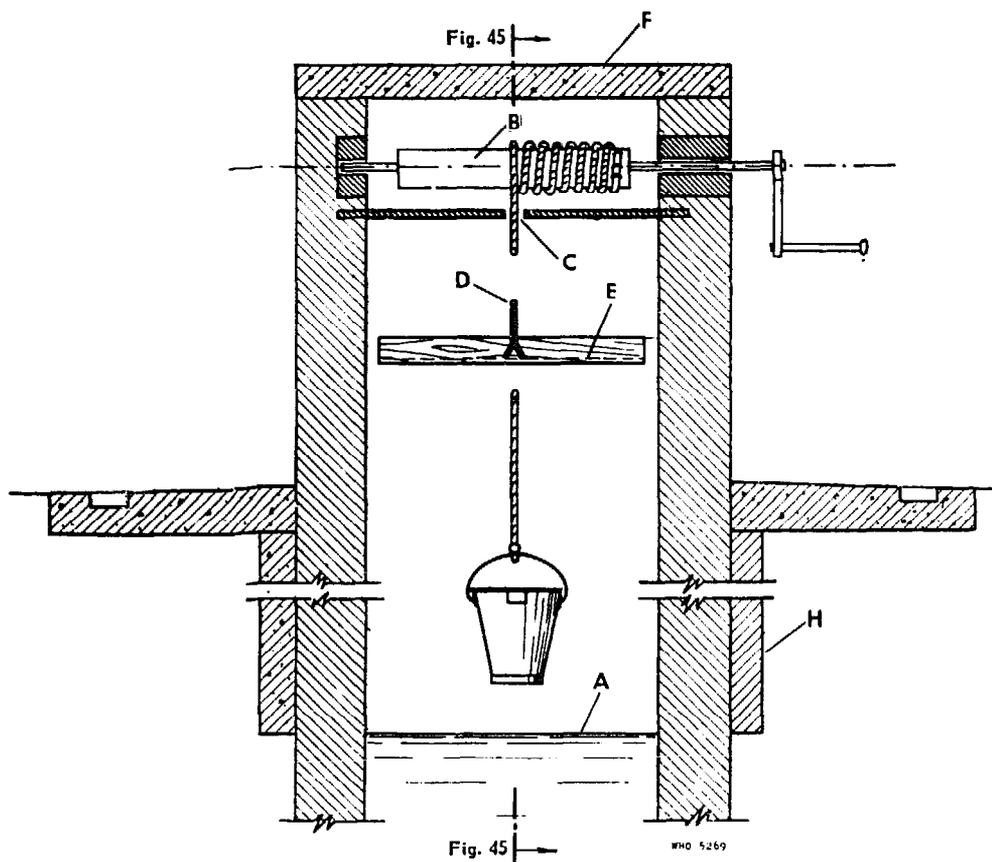
A = Water level in well   E = Trough
B = Windlass   F = Tight cover, removable
C = Guide hole for rope   H = Compacted clay,
D = Stop hook   or concrete grout

Fig. 45. A SANITARY ROPE-AND-BUCKET WELL (II)
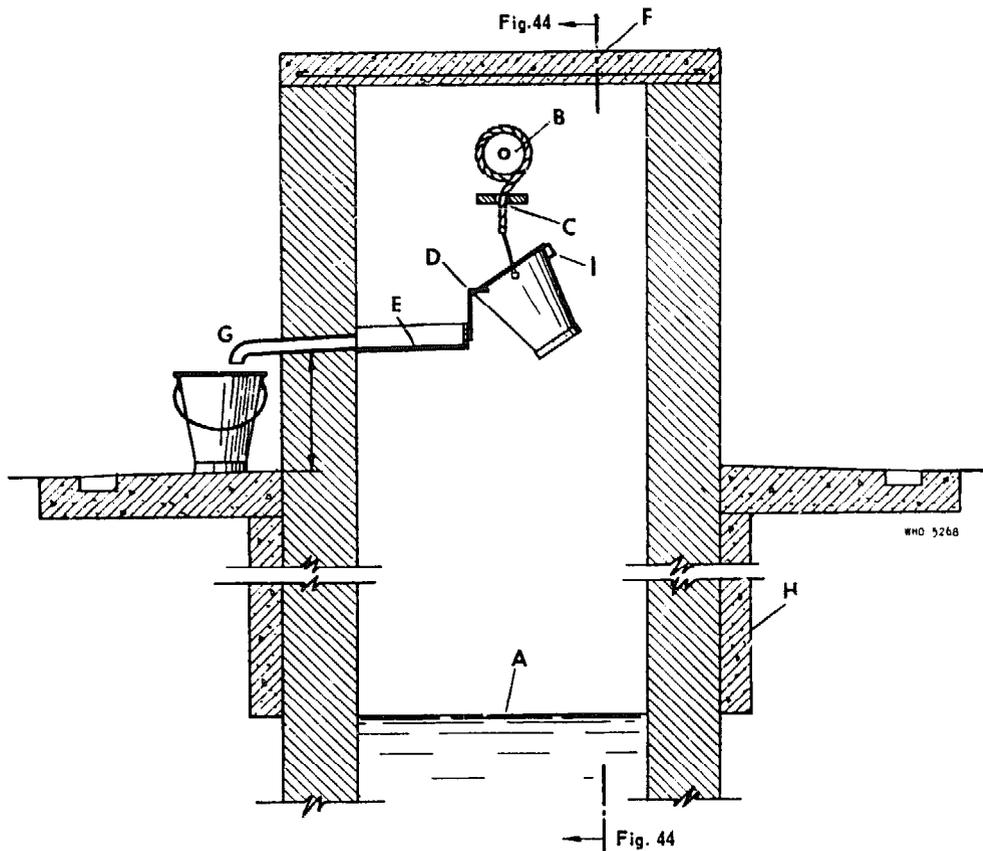
A = Water level in well	F = Tight cover, remov-	I = Weight attached to
B = Windlass	able	top side of bucket
C = Guide hole for rope	G = Discharge opening	to make it tilt when
D = Stop hook	H = Compacted clay, or	bucket is lowered
E = Trough	concrete grout	onto water surface

standard iron pipes and fittings and other materials put together by village craftsmen. Since the handles on hand-operated reciprocating pumps are most susceptible to breakage from rough usage, wooden handle assemblies have sometimes been successfully built out of materials available in rural areas.[a,b]

The *semi-rotary pump*, double-acting or quadruple-acting type, is often used in individual water-systems in rural areas for low lifts of water from wells, cisterns, and underground reservoirs to overhead tanks. Fig. 43 illustrates the operation of a double-acting, semi-rotary pump. Without a

[a] American Friends Service Committee (1956) *Social and technical assistance in India; an interim report*, Philadelphia (Unpublished document)

[b] Perlas, J. C. & Navarro, P. (1957) *Rural water-supply in the Philippines* (Unpublished working document WHO/WPRO/Env. San./Z11, W.P.11)

foot valve, these pumps are satisfactory for only very small suction lifts. When a foot valve and a strainer are fitted to the bottom of the suction pipe, the pumps will operate with a suction lift of up to 6 m (20 ft).   Their capacity depends upon the number of strokes of the handle per minute.

Other types of displacement pumps are in most instances powered by hand or animals, and are used for low lifts of water from cisterns and dug wells for irrigation or domestic purposes.   They include :

(1)   the rope and bucket systems, sometimes operated by means of a windlass (Fig. 44, 45);

Fig. 46. CONTINUOUS-BELT BUCKET   Fig. 47. MULTICELLULAR BAND PUMP
              PUMP
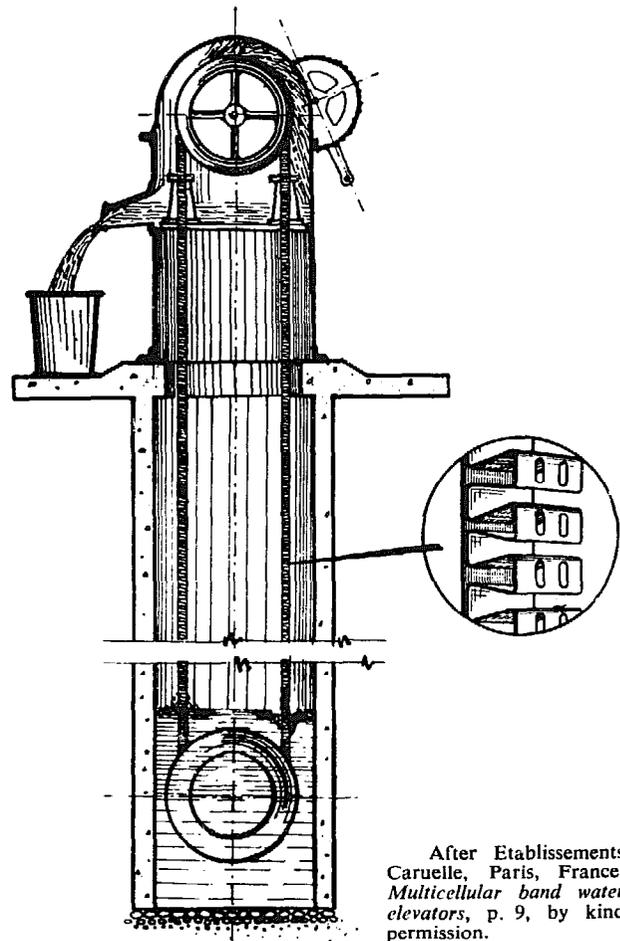
After Etablissements
Caruelle, Paris, France,
*Multicellular band water
elevators*, p. 9, by kind
permission.

Water is elevated in small buckets attached to a belt which continuously carries it to the surface. This is a fairly foolproof system, with little maintenance required. The original cost is considerable, but the pump could be made locally from local materials. Note the location of openings (A) of buckets.

The band pump works on the principle of elevating water which is fixed to the folds in the band by surface tension. This pump is rather high in initial cost but gives long service with few maintenance problems.

(2) the chain bucket pump, which consists of a series of metal buckets attached to an endless vertical chain extending below the water level; as the chain is revolved, the buckets pick up water and are carried upward over a toothed wheel or a trough into which they empty themselves (Fig. 46);

(3) the chain-and-plug pump, which consists of a series of rubber, hemp, or wooden plugs or pistons fitted to an endless chain moving inside a metal or wooden pipe immersed in the water; the plugs form a close fit with the pipe's interior surface and push the entrained water upward to a discharge-spout situated at the top of the well;

(4) various types of water elevators, which consist of an endless metal band folded in such a manner as to create a large number of small, open-end, horizontal cells (multicellular band) which retain the entrained water and discharge it into a trough when they pass over a pulley at the top of the well (Fig. 47).

With the chain pumps mentioned under (2), (3), and (4) above, it is necessary that the water level in the well should remain fairly constant and should not be subject to wide seasonal extremes.

Velocity pumps

In velocity pumps, water is moved through the continuous application of power by some mechanical means. In the centrifugal pump, energy

Fig. 48.   CENTRIFUGAL PUMPS: TURBINE-TYPE (I) AND VOLUTE-TYPE (II)
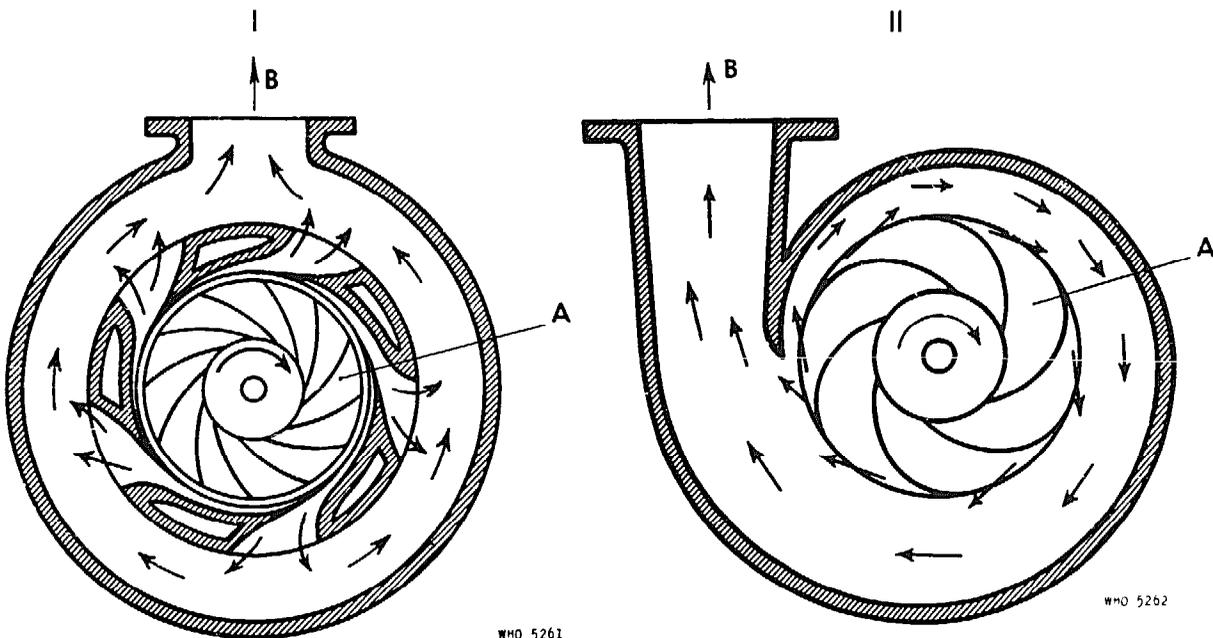
The rapidly rotating impeller (A) supplies energy to the water, causing it to flow out through the opening (B).

Fig. 49. CENTRIFUGAL PUMPS : DIRECTLY CONNECTED TO POWER UNIT (I) AND
WITH BELT-DRIVE (II)
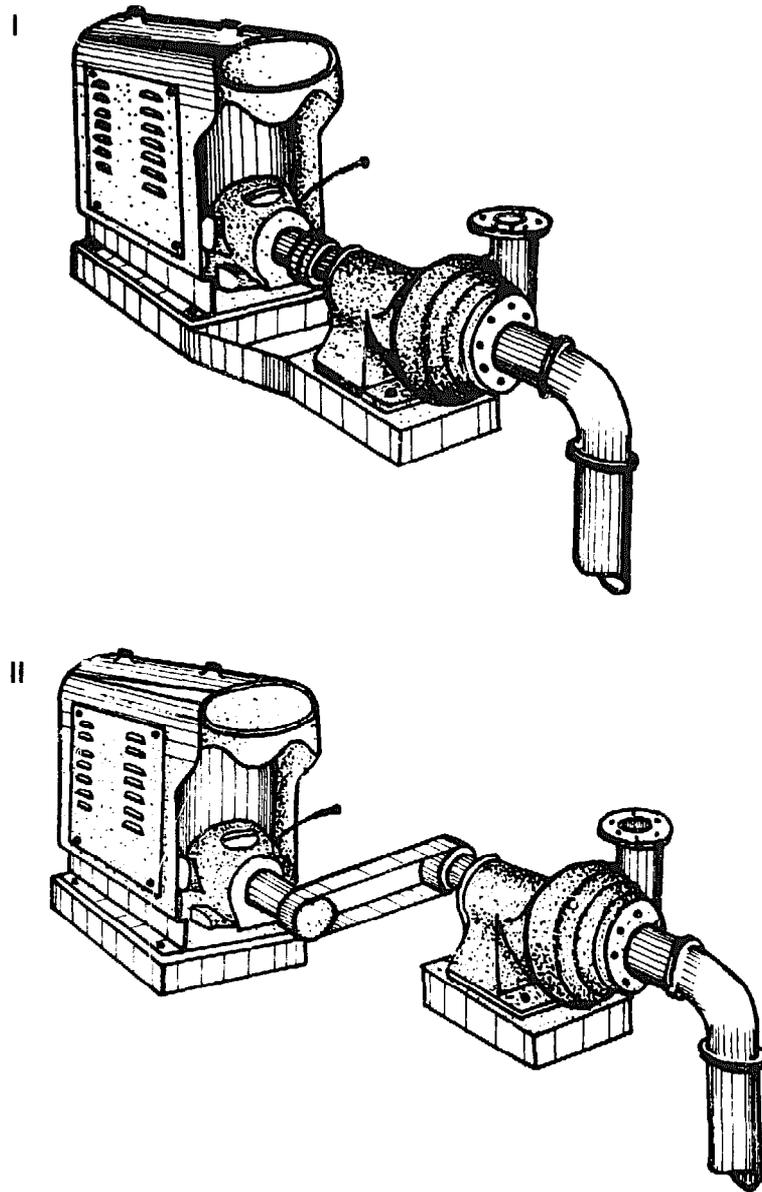
This is the best and simplest arrangement for centrifugal pumps. Power unit may be electric motor or internal combustion engine.

Belt-driven centrifugal pumps are common but introduce belt maintenance.   Necessary in order to get the correct engine-pump speed ratio.

The manufacturers' recommendations for operation and maintenance should be followed.

is applied by a rapidly rotating impeller in which kinetic energy is transformed into water pressure (see Fig. 48, 49); as a result, water is propelled out of the discharge opening.   In the jet pump, the kinetic energy of the

Fig. 50. JET PUMP   Fig. 51. TYPICAL INSTALLATION OF JET PUMP
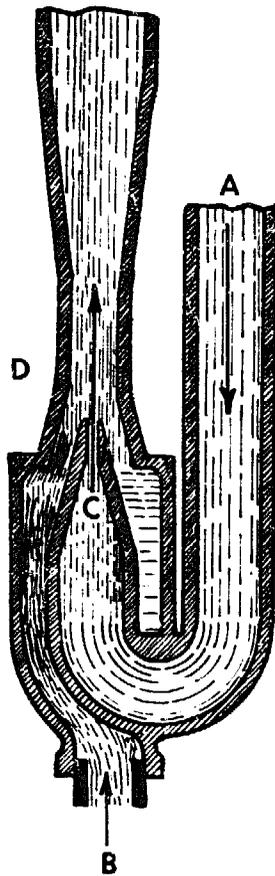
WHO 8263

A = Water being return-
ed from pump above
B = Water from well
being sucked up into
throat (D) by high-
velocity discharge
(C)
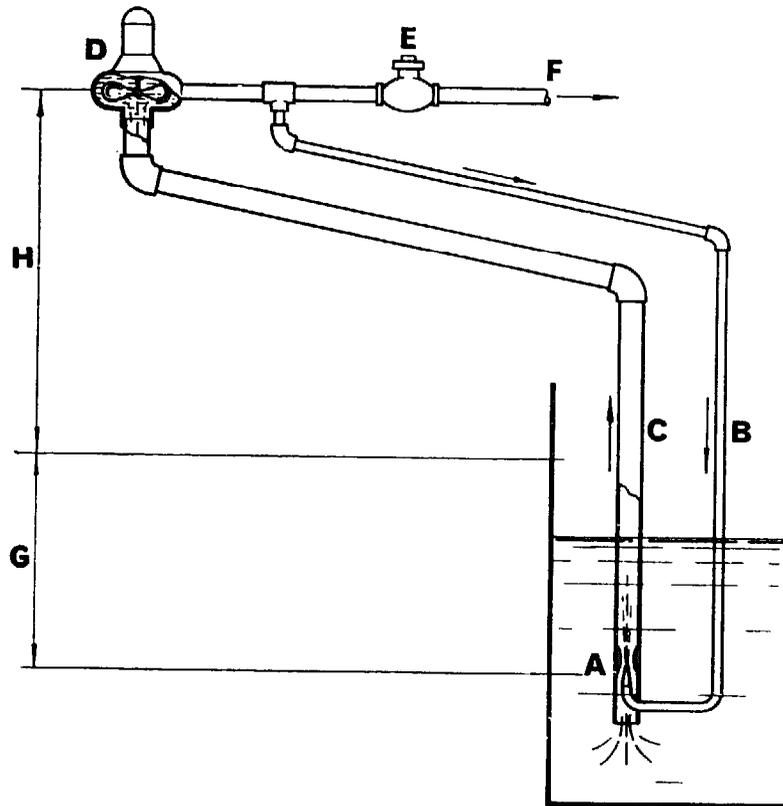
A = Jet assembly
B = Water line from pump to nozzle
C = Rising water
D = Centrifugal pump
E = Pressure-regulating valve
F = Discharge pipe
G = Height of water pushed by jet
H = Suction by centrifugal pump (about 4.5-6 m,
or 15-20 ft)

high-velocity jet of water or steam is converted into water pressure in the portion of the suction pipe immediately following a restricted opening or throat similar to the discharge half of a venturi meter (Fig. 50, 51).

Velocity or rotary pumps, while all working on the centrifugal principle, are usually known as either centrifugal or turbine pumps. In the centrifugal type the water enters at the centre of the impeller and leaves at the periphery—in other words, the flow is radial—while in the turbine type the water flows in the general direction of the axis of the pump through a number of stages. Fig. 48 and 52 illustrate this difference.
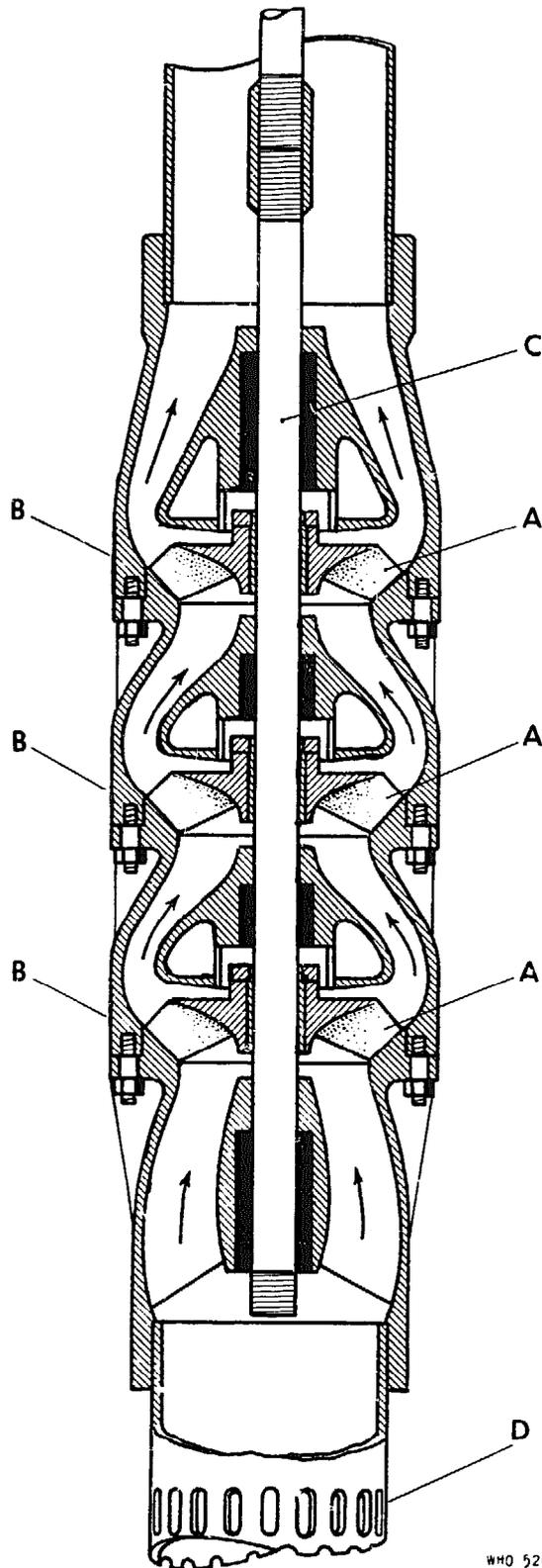
Fig. 52. SECTION
OF TYPICAL DEEP-WELL
TURBINE PUMP

C

B

A

B

A

B

A

A = Impellers
B = Stages
C = Shaft
D = Strainer

In the turbine pump, wa-
ter is lifted from one stage
(B) to next by small impellers
(A) being rotated by shaft (C),
which is attached to power
unit. The number of stages
and the design of the impel-
ler vary with the pumping
requirements. This pump is
highly efficient and, when
properly operated and main-
tained, gives long service.

D

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Both centrifugal and turbine pumps (particularly the latter) can be of very high efficiency, but this efficiency is usually dependent on a carefully calculated, narrow range of duties. In other words, each pump must be designed for the exact duty it has to perform; and the more it varies from that duty the less efficient it is. Centrifugal pumps may, of course, be designed with a wider range of duties—i.e., with a flatter performance curve—but very high efficiencies are not obtainable with such designs.

An advantage possessed by turbine pumps, particularly, is their compactness. Very powerful pumps can be built into small-diameter bore-holes; and, when large quantities of water are required from a bore-hole, this type is usually chosen in preference to a displacement pump. In addition they work at much higher speeds, and the transmission mechanism is lighter and more compact, though the increased delicacy of this mechanism renders it more liable to breakdown and more difficult to repair. Speed of operation, too, is more critical; and, with rural electricity supplies, or with inadequately maintained petrol or diesel engines, pumps may run at greatly reduced efficiency because the rate of rotation falls below that for which they were designed.

As a general rule, single-stage centrifugal pumps are used for situations where a low suction lift, medium pumping-head, and large quantities of water are required, such as river intakes, shallow wells, or low-pressure boosting; and turbine or multi-stage pumps are used where compactness is essential or high pumping-heads are required, such as bore-hole intakes or high-pressure boosting.

Jet pumps, sometimes referred to as ejector pumps, are less efficient than any of the types mentioned so far but have certain advantages which make them suitable for very small water-supplies where conditions favour their installation. Essentially a jet pump consists of a small, centrifugal pump which forces water down a well at high pressure. This high-pressure water, issuing from a jet into the throat of a venturi tube (see Fig. 50), causes a larger volume of water at lower pressure to be delivered from the rising main. Of this delivery, a quantity equal to the high pressure operating water is recirculated through the pump, the useful delivery being the difference between the two quantities. Priming is necessary since, until the whole system is filled, operation will not start; and, unless this can be done by means of a return feed from the storage tank, there is danger of pollution.

There is little advantage in fitting a jet pump where the depth to water level is less than 6 m (20 ft), as a simple centrifugal pump will perform the same duties more efficiently. The normal limits of duties of the small jet pump are a lift below ground of 6-30 m (20-100 ft) and a discharge of up to 75 litres (20 US gal.) per minute against a delivery head above ground of 15 m (50 ft) or thereabouts. At all times the jet must be covered by at least 1.5 m (5 ft) of water, so that the well cannot be completely emptied.

A jet pump is light and compact and has all moving parts on the surface. When polythene or other flexible delivery and operating pipes are used, it is very quickly installed; and the unit can operate in a narrow bore-hole. The pump and motor are mounted to one side of the hole, thus leaving the well top clear.   For this reason a portable jet pump may often be used for emergency supplies and can be quickly transferred from one source to another.   A further advantage is its ability to pump water containing sand or silt, provided, of course, that it is possible to separate such abrasive material from the portion of the water which is recirculated to the pump for operating the jet.

Some typical figures for small jet-pump performance, using a diesel prime mover of 1½ h.p. or electric motor of 1 h.p. are as follows :

Water level, 12 m (40 ft) below ground; delivery head, 15 m (50 ft) above ground; capacity, 55 litres (15 US gal.) per minute

Water level, 24 m (80 ft) below ground; delivery head, 30 m (100 ft) above ground; capacity, 20 litres (5 US gal.) per minute.

Characteristic curves

Usually a centrifugal pump is designed to give a specified discharge against a specified head at maximum efficiency for a given pump speed. However, there is a moderate range over which, at or near maximum efficiency, a greater discharge may be obtained against a reduced head or a lower discharge against a greater head, and a much larger range over which varying discharges can be obtained at lower efficiencies.   A curve can be prepared showing the relationship between the quantity pumped and the total pumping-head for any given pump speed.   This curve, and curves showing the relationship between the quantity pumped and horsepower absorbed and between the quantity pumped and the percentage efficiency, are known as the pump characteristic curves.

Fig. 53 shows the characteristics of two different 8-cm (3-in.), two-stage pumps (A and B) running at 1450 r.p.m. and of a five-stage, submersible pump (C), running at 2900 r.p.m., suitable for installation in a 20-cm (8-in.) internal diameter bore-hole. Fig. 53 D is a chart from which it is possible to choose suitable deep-well turbine pumps.

(1)   *Quantity head-curve* : This curve shows that, as the pumping head decreases, the quantity pumped increases.   The head shown for zero quantity is known as the " shut-off " or " closed-valve " head, and is the head generated when the pump is running with the delivery valve closed. With some pumps the head decreases progressively as the discharge increases from zero, (e.g., pump A), whereas with others the head begins to rise and then falls, as with pump B.   This is not important in the case of pumps working singly; but, where two pumps may run in parallel, it is essential that the closed-valve head be greater than the total pumping head when the two pumps are discharging together.

In most cases the curve has a flat slope at the low discharge end, and a small increase in pumping head can result in a large decrease in the quantity pumped. It is undesirable to work on this portion of the curve.

(2) *Quantity efficiency-curve*: This curve increases from zero at zero discharge to a maximum at the discharge for which the pump is designed, and then falls off more rapidly, and often much more rapidly, than the rising portion. This curve indicates over which portion of the pump's range it can satisfactorily operate. In the case of pump A , there is a range of from 852 litres (225 US gal.) per minute against 56 m (184 ft) to 1230 litres (325 US gal.) per minute against 42 m (139 ft) over which efficiency is a little below the maximum; and, at from 568 litres to 1420 litres (150 US gal. to 375 US gal.) per minute, the efficiency is not unduly low. Outside this range, the efficiency is too low to permit satisfactory operation. Generally, the efficiency of centrifugal pumps available on the market ranges between 40% and 85%, the larger pumps being more efficient than smaller ones.

(3) *Quantity horsepower-curve*: In some cases, e.g., pump B, this curve is more or less a straight line, rising as the quantity increases, and the slope may even steepen as the quantity increases beyond that for optimum efficiency. In other cases, e.g., pumps A and C, the curve flattens or even falls off beyond this point. The latter type of curve is " non-overloading ".

It is necessary to provide a motor of adequate power to cope with the worst pumping conditions that may be encountered. In certain circumstances, as for example in the case of a pumping main to a storage reservoir which is also used as a distribution main, there may be a very considerable fluctuation in the pumping head at different times of the day, the maximum being when there is no draw-off and all the discharge is going to the reservoir, and the minimum being when all the supply is going to the distribution system. A pump must be selected which will have a satisfactory efficiency over the whole operating range; and, if it has a quantity—horsepower characteristic as in pump A or pump C, a smaller motor will suffice than would be necessary for a pump with a characteristic similar to pump B.

In the case of the submersible pump, C, the horsepower curve is nearly flat over the working range of the pump, giving flexibility of performance without the risk of overloading the motor. This is valuable for boreholes in which the water level may vary considerably.

The curves for deep-well turbine pumps are similar to those for submersible pumps except that for a given capacity and speed the efficiency is somewhat lower due to the horsepower absorbed by the long shaft and bevel gear or twisted belt drive.

Fig. 53 shows the characteristics of a submersible pump for five stages (pump C). The addition of stages to a turbine pump increases the head capacity in direct proportion to the number of stages without affecting the

Fig. 53.   TYPICAL CHARACTERISTICS OF DEEP-WELL TURBINE PUMPS
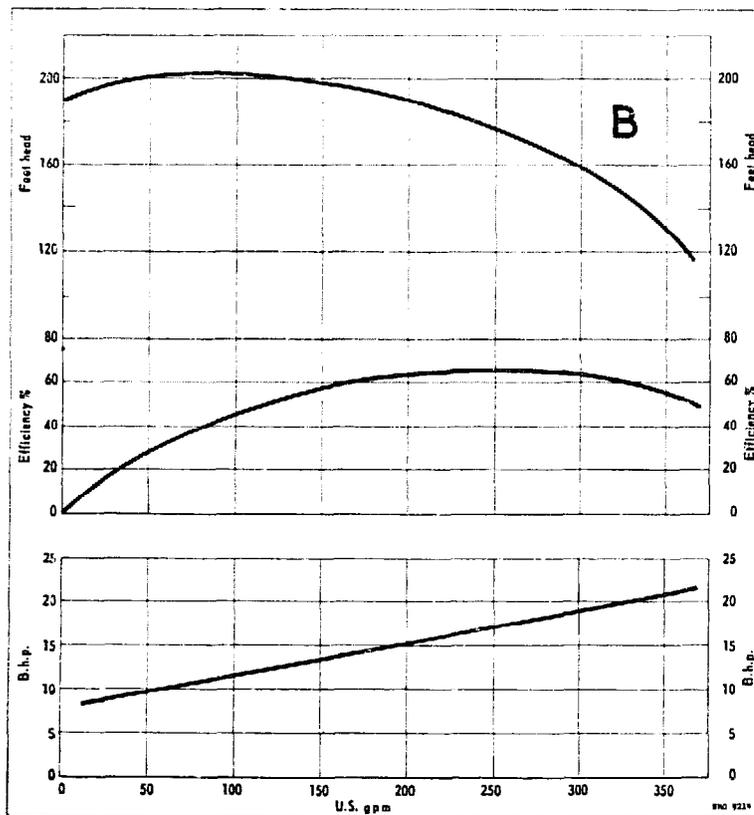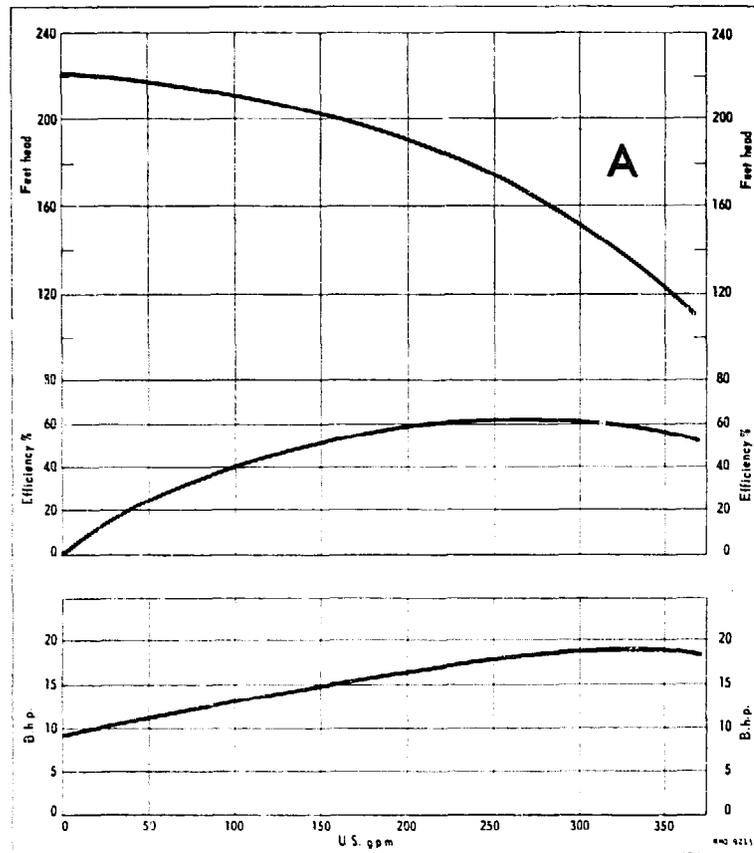
A, B = 3″ two-stage centrifugal pump, 1450 r.p.m.

Fig. 53. TYPICAL CHARACTERISTICS OF DEEP-WEELL TURBINE PUMPS (continued)
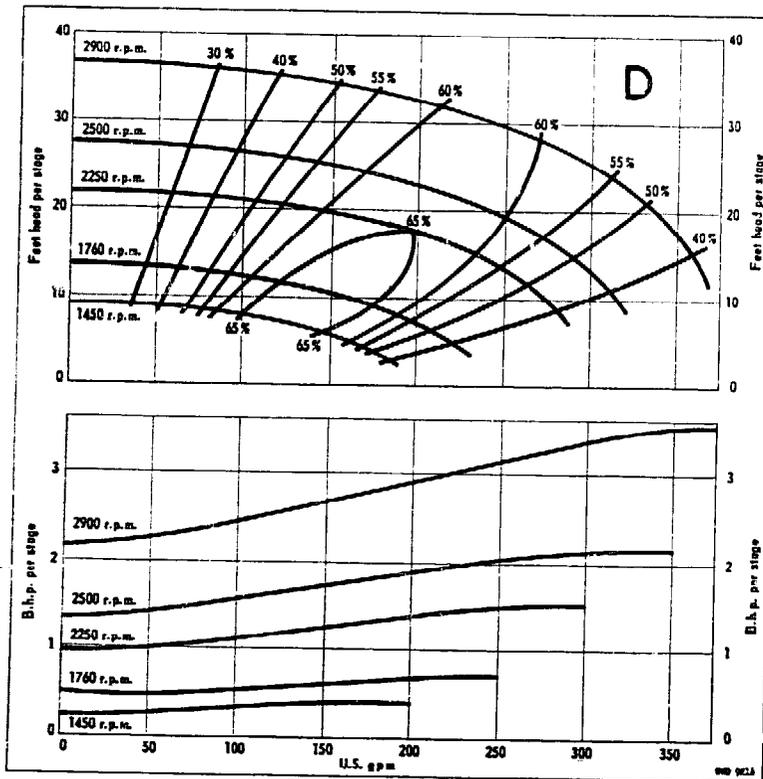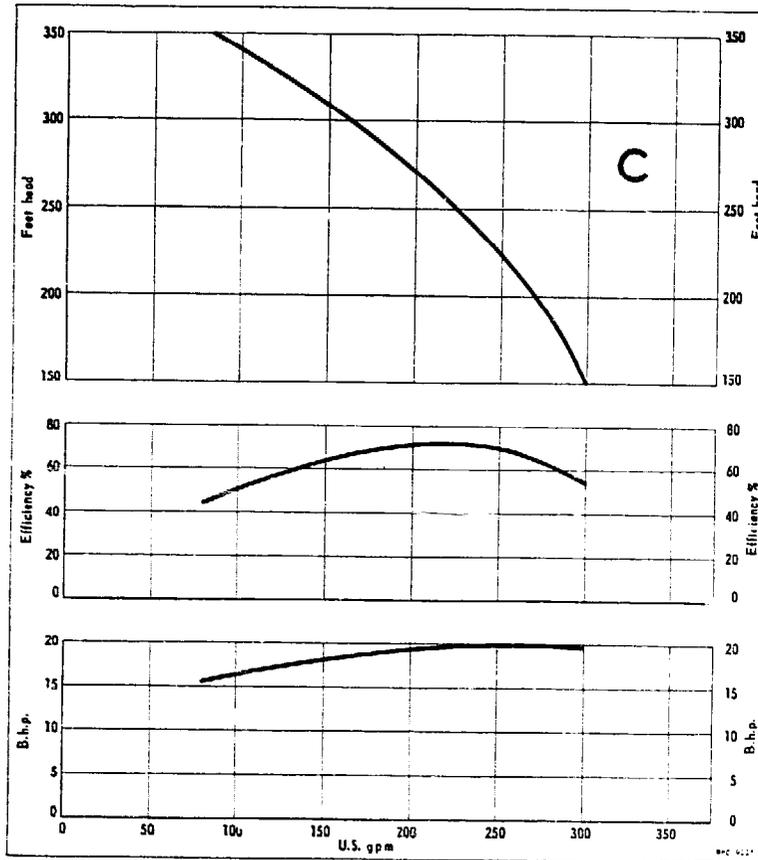
C = 7⁵/₈″ five-stage submersible pump, 2900 r.p.m.
D = 6″ deep-well turbine pump

quantity.   The horsepower absorbed also increases directly with the number of stages.   For about three or more stages the efficiency remains unchanged, but there is a slight reduction when there are only one or two stages.

The speed of a centrifugal pump has a considerable effect on its performance, the quantity varying directly as the speed, and the head varying as the square of the speed.   The horsepower absorbed is therefore proportional to the cube of the speed.   The efficiency tends to improve as the speed increases, but this depends on the design of the pump.   A high-speed pump is therefore lighter and cheaper than a low-speed pump of similar capacity.   However, increase in speed tends to lead to increased maintenance costs, and a suitable balance between original costs and maintenance costs has to be adopted.

Usually the characteristic curves of a pump are plotted separately for each particular speed; but they may be shown for a number of speeds, as in Fig. 53 D, which gives the characteristics of a deep-well turbine pump per stage for speeds varying from 1450 r.p.m. to 2900 r.p.m. Characteristics for intermediate speeds may be interpolated.

These curves, which are applicable to a particular pump operating at a specific speed, change with the width and design of the pump's impeller. An impeller with more vanes (see Fig. 54) produces flatter performance curves; so does an impeller with more radial or wider vanes.   An impeller with a large suction eye produces more water.

Suction lift is also of great importance when dealing with centrifugal pumps.   When it is close to the theoretical maximum (approximately 10 m, or 33 ft), a very inefficient operation will result; and wear and tear on the pump's moving parts will be speeded up.   This is show graphically in Fig. 55.   Here the total lift or head is assumed to be 10 m (33 ft). A pump installed 3 m (10 ft) above water surface will lift the water 7 m (23 ft) above its centre, while the same pump installed with a suction lift of 8 m, or 26½ ft (i.e., 80% of the theoretical maximum of 10 m), will raise the water only 2 m (6½ ft) above its centre.   Such a situation may arise in a well in which the draw-down due to pumping is excessive; this is illustrated by the typical capacity curves shown in Fig. 55.   It is important, therefore, to test a newly constructed well for draw-down and yield and to install the centrifugal pump in such a manner that its centre will never be more than about 5 m (16 ft) above the lowest water-level obtained in the well when pumping.

It is normally only in the case of pumps of large capacity that such pumps are designed specially for the duty to be performed.   Manufacturers produce a large range of standard pumps to cover varying arrangements of quantity and head; and, by modifications of impeller sizes, and sometimes of speeds, one of these standard pumps can be adapted to suit, more or less closely, any pumping duty over a wide range.   For any given duty, a pump made by one manufacturer may be more closely adapted than those of other

Fig. 54. EFFECTS OF VANES AND SIZE OF INTAKES ON PERFORMANCE CURVE AND CAPACITY OF CENTRIFUGAL PUMPS
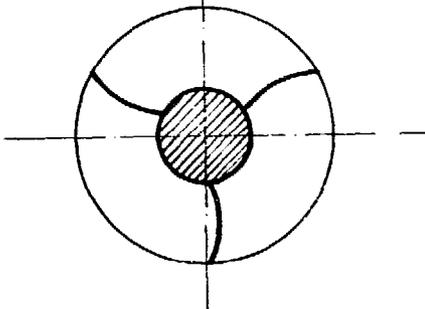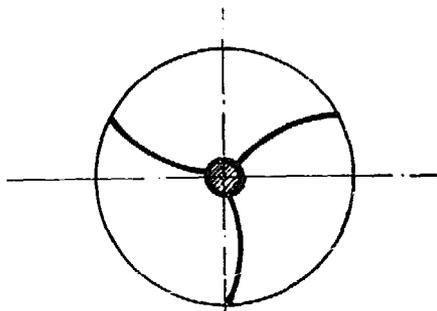
Larger intake—greater capacity
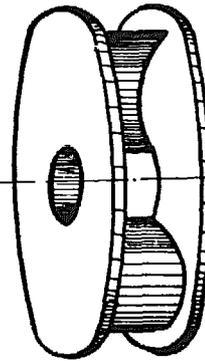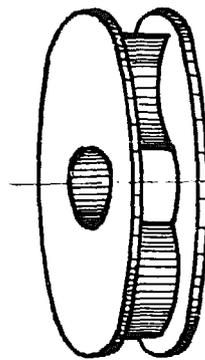
Wider impeller—flatter performance curve
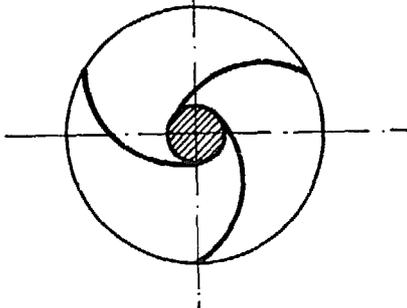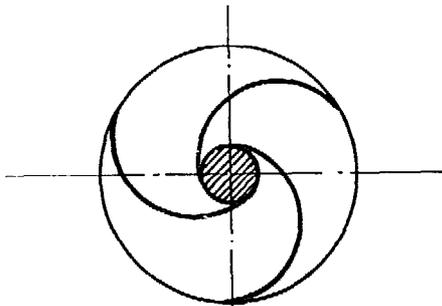
More tangential vanes—flatter performance curve
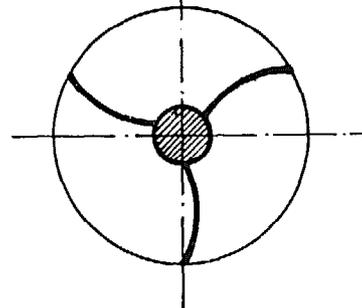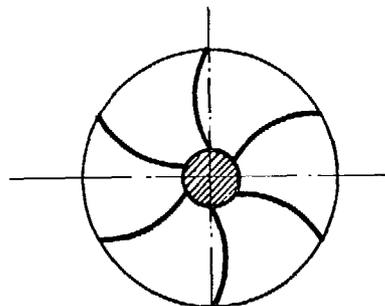
More vanes—flatter performance curve

10

Fig. 55. TWO PUMPING SITUATIONS, SHOWING CENTRIFUGAL
PUMP CAPACITY CURVES

A   B
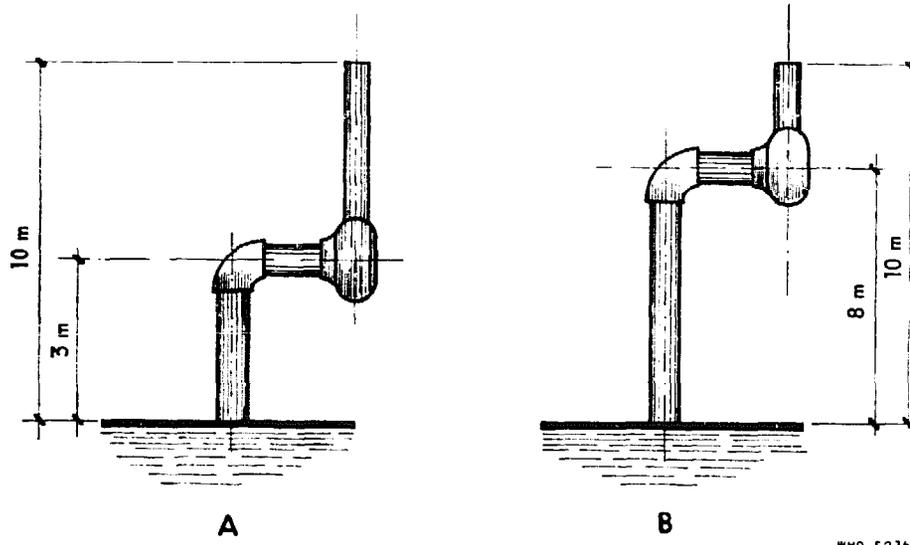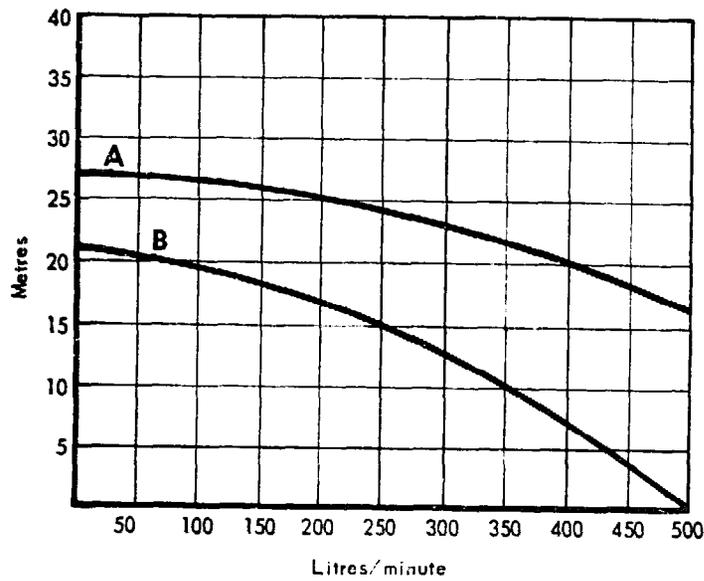
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WHO 5277

A = Performance curve when pumping with low suction lift
B = Performance curve when pumping with high suction lift

manufacturers; and it is by the study of the characteristics of the various pumps offered that a decision can be made as to which is the most suitable for a particular duty.

How to choose a suitable deep-well turbine pump

A deep-well turbine pump (see Fig. 52, 56, 57) is required to go into a 15-cm- (6-in.-) diameter bore-hole, and to give 662 litres (175 US gal.) per minute against a 30-m(100-ft)head. From the upper part of the chart in Fig. 53 it will be seen that at 1450 r.p.m. this type of pump will give 1.2 m (4 ft) head per stage at 662 litres (175 US gal.) per minute; in other words, a 25-stage pump will be needed to give a 30-m (100-ft) head with an efficiency of 50%. Similarly, at 1760 r.p.m., 11 stages will be required (efficiency, 65%); at 2250 r.p.m., 6 stages (efficiency, about 64%); at 2500 r.p.m., 4 stages (efficiency, about 61%); and at 2900 r.p.m., 3 stages (efficiency, 55%).

Fig. 56. DEEP-WELL TURBINE PUMP: ELECTRIC MOTOR (I) AND DIRECT DRIVE AND ANGLE-GEAR HEAD (II)

WHO 5281
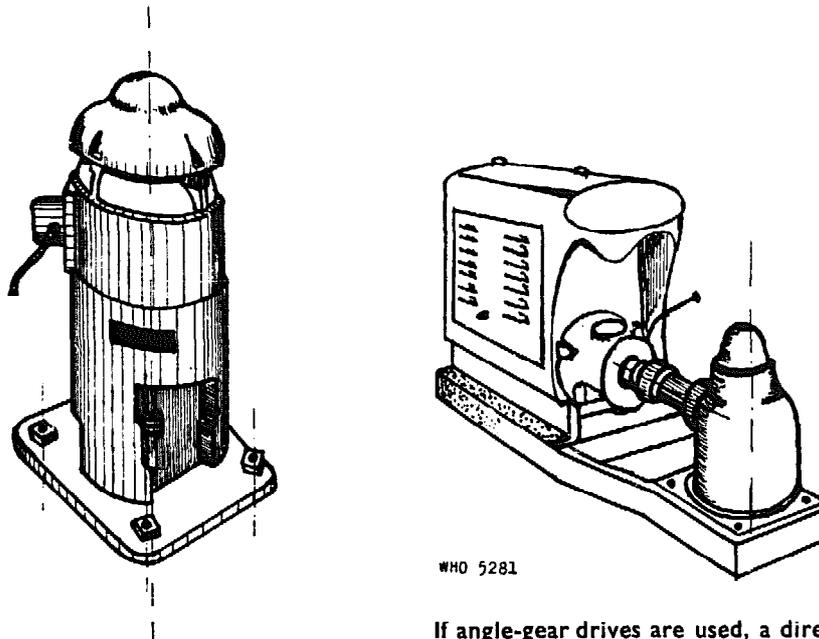
This is the best and simplest drive arrangement for deep-well turbine pumps. A reliable source of electricity must be available.

If angle-gear drives are used, a direct connexion is best, for belt maintenance is eliminated. Various gear ratios are available to get the correct engine-pump speed ratio. Angle-gear drives require careful lubrication and maintenance.

The manufacturers' recommendations for operation and maintenance should be followed.

Fig. 57.   DEEP-WELL TURBINE PUMP: DIRECT BELT DRIVE (I) AND BELT DRIVE AND
ANGLE-GEAR HEAD (II)

WHO 5282   WHO 5283
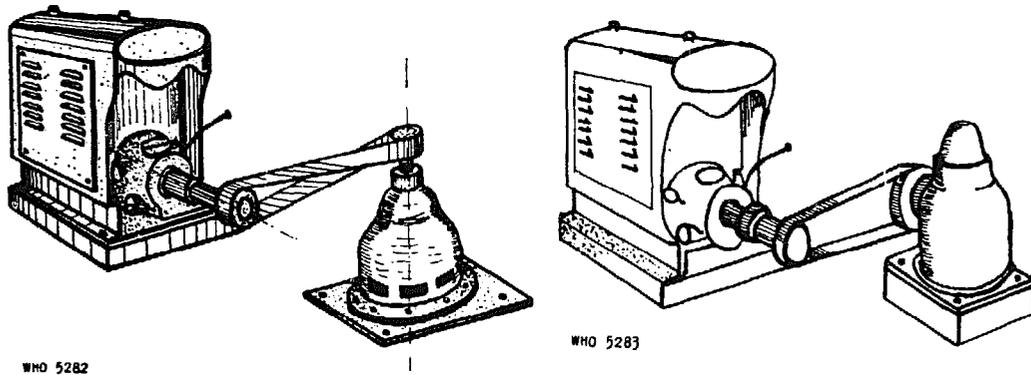
This is the cheapest drive but requires continual belt maintenance. Pump speed may be altered by pulley ratio.

This offers little advantage over direct drive with angle-gear head except the possibility of altering the pump speed through the pulley ratio. Belt maintenance is required. Angle gear requires careful lubrication and maintenance.

The manufacturers' recommendations for operation and maintenance should be followed.

From this it appears probable that the pump chosen will be an 11- or 6-stage pump at 1760 r.p.m. or 2250 r.p.m., but a check on the bottom part of the curve will give the power required. At 1450 r.p.m., 0.4 brake horse-power b.h.p. per stage will be needed; hence a 25-stage pump will require 10 b.h.p. to drive it. Similarly, at 1760 r.p.m., $11 \times 0.65 = 7.15$ (b.h.p.) will be necessary; at 2250 r.p.m., 8 b.h.p.; at 2500 r.p.m., 7.28 b.h.p.; and at 2900 r.p.m., 8.4 b.h.p. The most suitable pump, therefore, is an 11-stage pump which will absorb 7.15 b.h.p. for the duty envisaged.

This is the horsepower absorbed. If a direct-coupled electric motor is to be used, approximately 10% should be added for transmission losses, and an 8-h.p. motor would be chosen. If a diesel engine is used to drive the pump, either direct-coupled through a bevel head and gearbox or by a twisted belt drive, then about 33½% will be necessary to allow for the extra losses, and a 10-h.p. engine would be chosen.

Buoyancy pumps

In the air-lift pump, water is raised from its static level in a well by mixing it with air, thus changing the specific gravity of the mixture. The main parts of such a pump are shown in Fig. 58. By means of a compressor, air is forced down the well through a small pipe placed inside the eduction-pipe. The air-water mixture, being lighter than the water outside the eduction-pipe, rises to the top of the well.

This pump has the great advantage that there are no moving parts within the well, all power and moving equipment being located above ground. It is often used for drawing water from drilled wells in which the water level is at a considerable depth below the ground. It is also well adapted to pumping dirty or sandy water and for drawing water from crooked wells, i.e., wells which are not straight and vertical.

For proper operation, it is necessary that the eduction pipe be from 50% to 70% submerged in the ground water for pumping against heads up to 61 m (200 ft). This, of course, means that existing wells, if they are to be fitted with air-lift pumps, may need to be deepened in order to secure adequate submergence of eduction-pipes. In areas where the ground-water level fluctuates greatly or where the draw-down during pumping is considerable, this type of pump may not be used. Another disadvantage is that water cannot be pumped any appreciable distance horizontally. The efficiency of the air-lift pump is usually low, around 20%-50%. For this reason, and also because of the high cost of air compressors, this system should be carefully investigated before being employed in small and rural water-supply systems.

Fig. 58. MAIN PARTS OF AIR-LIFT PUMP
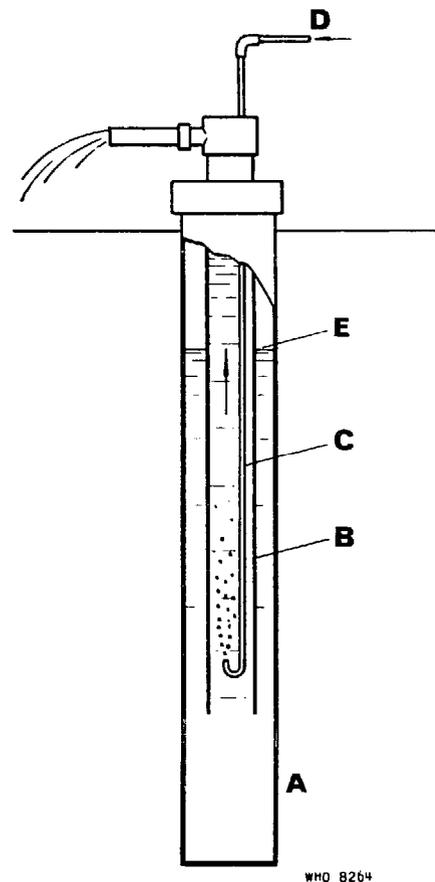
WHO 8264

A = Well casing
B = Eduction pipe
C = Air pipe
D = Air under pressure from compressor
E = Level of water in well

Impulse pumps

In the hydraulic ram, power is derived from the water hammer that is intentionally produced (Fig. 59). The force of the water is captured in a chamber where air is compressed and released when the compressed air expands, pushing a small amount of the water to a higher elevation than that from which it originally came. The water not raised up to a higher level is wasted. At each compression and decompression of the air in the chamber, a definite quantity of water is pushed up to the tank or reservoir.

Fig. 59.   HYDRAULIC RAM

A = Supply—litres/minute
B = Difference in elevation between ram and supply-power head
C = Length of drive pipe
D = Difference in elevation between ram and highest point to which water is to be elevated—pumping head
E = Total length of supply pipe
F = Stand-pipe, necessary in case of exceedingly long drive pipe

Under the proper circumstances—a situation similar to that shown, in which the supply of water is considerably in excess of the needs, and is situated so that the ram can be located well below the supply—the hydraulic ram can be an excellent solution to a pumping problem.

When writing to manufacturers about ram sizes, the information in items A, B, C, D, and E is necessary. With this the factory will be able to recommend the correct size, feasibility, etc.

Where a continuous supply is available—from a spring, for example—this process can go on continuously; and a great deal of water is pumped over a 24-hour period.

The following tabulation gives an idea of the amount of water that can be pumped with various heads and amounts of power water : [32]

Ratio of pumping head to power head	2	3	4	5	6	7	8	9	10	12	15	20
Delivery in gal. per day for each gal. per min. of power water	540	345	240	192	160	137	120	107	96	80	64	43

It is rather uncommon to find suitable topographical conditions for the installation of hydraulic rams; but, when they exist, this apparatus is one of the most useful pumps to be considered, especially for individual water-supply installations. It is durable and inexpensive in initial cost. It requires practically no maintenance, and will work 24 hours per day with neither attention nor operating costs. However, only a small portion of the available water will be pumped. Unless the remainder of the operating water can be used in other ways (for crop irrigation, for example), it is wasted. When a supply is desired from a spring, or other supply source which has a good fall and a flow several times greater than is required for the water-supply system, then a hydraulic ram should always be considered as a possibility.

Other pumps similar to the hydraulic ram but employing differential cylinders as motive power may be found on the market. They have the advantage of being able to pump clean water from a well while using some other water, such as that from a contaminated stream, as motive power.

Selection of Pumps

It is not possible to establish strict rules for selecting pumps since there are so many factors capable of influencing a decision. The most important considerations are :

(1) the extent and reliability of the service which will be available for maintenance;

(2) the initial cost of the pump and its driving equipment;

(3) the cost of operation;

(4) the capacity and lift required;

(5) the sanitary features of the pumps available commercially;

(6) the desirability of standardization and reduction of the number and diversity of spare parts when smaller pumps are in operation.

Other factors include the type and size of wells, fluctuations of drawdown levels, location of pumps and engines, variations in load, etc.

As a general guide, the following advice may be given with regard to the selection of pumps for rural water-supply systems :

(1) Pumps in which all moving parts are above ground and easily accessible are preferable and will, in most instances, give the best service simply because they are easier to maintain with means available in rural areas. However, if, qualified maintenance can be assured, pumps with submerged cylinders should receive first consideration.

(2) Where motor power is used, efficiency is a very important factor; and the more expensive the power, the more important becomes the efficiency. In many places a new pump installed to replace an old, inefficient one would pay for itself within a very short time simply by reducing the cost of motor operation.

(3) Centrifugal and deep-well turbine pumps must operate under the conditions for which they were designed, or a great loss in efficiency will result. Pumps with flat efficiency curves are to be preferred for rural water-systems since they allow for greater flexibility in design, i.e., they eliminate the necessity of designing to precise limits. Consequently, such pumps will do varying duties under a substantial range of conditions; and, when adopted as standard equipment on several water-supply systems within the same rural area, they will facilitate maintenance and reduce the need for a multiplicity of spare parts.

(4) The pump selected should be one for which repair and replacement parts can be obtained easily and promptly.

(5) The pump equipment should be so constructed and installed as to prevent the entrance of contaminating water or material either into the well or into the water that is pumped. Special attention should be paid to the following sanitation specifications : [37]

(a) The pump head should be designed to prevent contamination by hands, dust, rain, birds, flies, and similar sources from reaching the water-chamber of the pump. Ordinary lift pumps with slatted pump-head tops should not be used for domestic water-supply systems.

(b) The pump base should be so designed as to facilitate a waterproof seal with the well cover or casing.

(c) The pump selected should be so designed and installed that priming will not be necessary.

When ordering or inquiring about a pump, the following information should be specified :

(1) the inside diameter of the smallest part of the casing or hole in which the pump is to be installed;

(2) the static water level in the well or reservoir, measured in metres (or feet) below land surface or other reference point;

(3) the desired yield, in litres per minute (or in gallons per minute);

(4) the draw-down in metres (or feet) or the lowest water level expected when pumping at the desired yield (in the case of a well, this should either be measured during a test of the well, or carefully estimated from the best available information on similar wells nearby);

(5) the desired water pressure at ground level, i.e., the operating pressure of any pressure tank (if any), the height of any elevated tank or standpipe, plus the friction in the delivery pipe;

(6) the type of power available (if electricity, full specifications—for example, 220 volts, 3-phase, 60 cycles, alternating current—should be given);

(7) the total depth of the well or reservoir.

It should also be stated whether the well is straight, at least down to the level at which the pump is to be set.

For all reciprocating deep-well pumps, whether operated by hand or by one or another source of power, the important feature is the extractable cylinder. By specifying a cylinder size smaller than the riser pipe, it is possible to use a submerged cylinder with operating parts that can be drawn up through the riser pipe for inspection, repair, or replacement. The alternative is to use a riser pipe of the same diameter as the suction or tail pipe and to draw the whole system when repairs are needed. Another important point is to require that the handle, fulcrum, and bracket on such a pump be made of malleable iron, and not of cast iron, which is brittle and breaks under repeated shock or impact, as it often does in operation or transport. A typical specification for a deep-well, hand-lift pump is given in Annex 6, page 296.

Power for Pumps

The cost of pumping is mainly the cost of power to operate the pump, so that in areas of limited economic means the use of power is of the utmost importance. Anything that Nature has provided should be used to full advantage. As a matter of fact, the type of power available will be in many instances the determining factor in the design of the rural water-system. This, of course, is often a function of available economic resources, but it is not always so.

The types of power that are available are as follows.

(1) Man power and animal power are the oldest, and in many places the only, kind available. Animal power can be completely adequate and should not be overlooked nor underestimated.

(2) Gravity is the cheapest source of power when it is possible to use it. Extensive effort should be made to find a solution in which water will flow to the consumer by gravity. Considerable extra initial cost is justified for such a solution. Usually an economic formula can be worked out based on the life and cost of pumping and equipment as compared to the cost of a pipeline to bring in water by gravity. In hilly, rough country there are ample opportunities for gravity supplies. Experience in Latin America would indicate that for small communities this is by far the preferred solution from the point of view of maintaining continued service. Almost without exception small towns with gravity systems are satisfactorily supplied with water at all times. Local materials can often be used to build gravity pipelines, thus further reducing the project cost.

(3) Wind (see page 155) is another very cheap source of power which should be given careful consideration in either individual or community supplies.

(4) Steam is usually not practical; but in areas with dense vegetation and lacking in other resources, it may be a good possibility. Small wood-burning boilers are not unreasonably expensive; and in jungle areas where wood is being produced prolifically, this source of power may be a good

solution. Once installed, a wood-burning boiler is a cheap and simple installation to maintain. Small steam-systems have been in operation in the Amazon Valley of Brazil for as long as 30 years with little or no maintenance, and they are still working.

(5) Electricity is to be preferred if it is available at reasonable cost, i.e., from some central supply. Electric motors are reasonably low in original cost and are cheap to operate. They require very little attention and give long service. Electricity has a very wide range of application, from the smallest fractional horsepower motors to " giants " far beyond the scope of this monograph. Small water-supplies in towns and homes require small units whose needs are perfectly met by the use of electric motors. On the other hand, it is unwise, in most rural areas, to attempt to generate electricity for the specific purpose of driving electrical equipment. Small electric generating units give so much trouble, especially in the tropics, and need so much specialized maintenance, that their installation should not be contemplated except in extremely rare cases.

(6) Internal combustion engines (gasoline or petrol, diesel, kerosene), in spite of being expensive and, in somes instance, difficult as well as costly to maintain, are the types of motor power which are often required for most small community supplies in rural areas. Experience in such areas would indicate that diesel engines are generally the best from all points of view, even though they are the most expensive in original cost. Heavy, low rotary-speed, diesel engines can give long service with a minimum of maintenance and low operating cost. Natural gas engines are also low in operating cost and are of long life, but they are not generally practical. Gasoline and kerosene engines are high-speed motors with short life and high operating cost and are useful only in certain places—Venezuela, for example, where gasoline is cheap. Besides the cost of power, the following items must be considered when the actual cost of pumping water is calculated : interest on, and depreciation of, the equipment, the wages of operators, the efficiency of the pumps, and the depreciation of the building cover. In the USA, the cost of pumping one million US gallons (3785 m³) through a height of one foot (30 cm) varies from 2-3 cents to 30-40 cents, 10 cents being considered a reasonable figure. [21]

The b.h.p. required to drive a pump is calculated by the following formula :

$$\text{b.h.p.} = \frac{Q \times H}{3960 \times e}$$

where

Q is the pump discharge in US gallons per minute,

H is the total head in feet pumped against, and

e is the pump efficiency expressed as a decimal.

The total head (H) includes the feet difference in elevation between the low-water level during pumping and the point of discharge, the loss of head

in the suction and delivery pipes, and minor losses of head due to strainer, valves, entrance and exit of pump, etc.

Windmills

Fig. 60. WINDMILL

Energy which Nature has provided, such as the wind, should be taken advantage of whenever possible. In many Northern European and Western Hemisphere countries, wind energy is used for pumping water for farms, homes, and small communities. This method (see Fig. 60) is excellent for obtaining a steady flow of water from a well at a very low cost.

For proper operation, the following conditions must be met:

(1) winds of more than 8 km per hour during at least 60% of the time;

(2) available windmill equipment;

(3) wells that can be pumped for many hours' duration each day;

(4) storage capacity of three days' supply (or more) to take advantage of long pumping periods and to provide for calm periods when there is no wind;

(5) clear sweep of wind to the windmill. This can be obtained by the use of a tower to raise the windmill 4.5-6 m (15-20 ft) or more above the surrounding obstacles.

The pump used in connexion with windmills is usually of the reciprocating type and has an extension of the piston rod above the upper guide with a hole for connexion with the pump rod from the windmill (see Fig. 61, 62). Provision may also be made for pumping by hand or for using animal power when extremely long periods of calm are likely to occur. The gearing on windmills varies with manufacturers and wind conditions: some pump one stroke with each revolution of the mill, while others pump one stroke with three or four revolutions. The former requires more and higher-velocity winds; the latter is advantageous in areas where there are winds of low velocity much of the time.
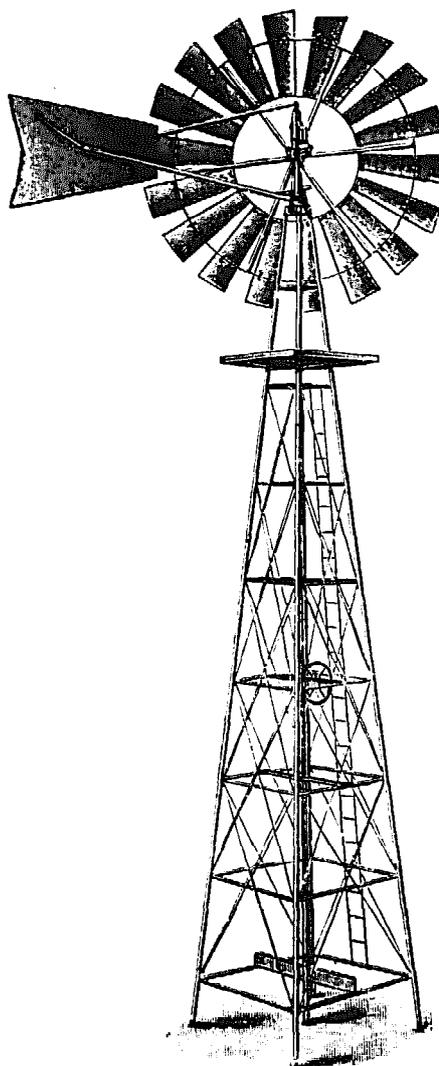
Fig. 61. PROPERLY DESIGNED
HAND OR WINDMILL PUMP WITH
CYLINDER ABOVE GROUND

A = Tight joint
B = Down-turned spout
C = Stuffing box
D = Brace to protect
joint (A) from
excessive strain

WHO 5251
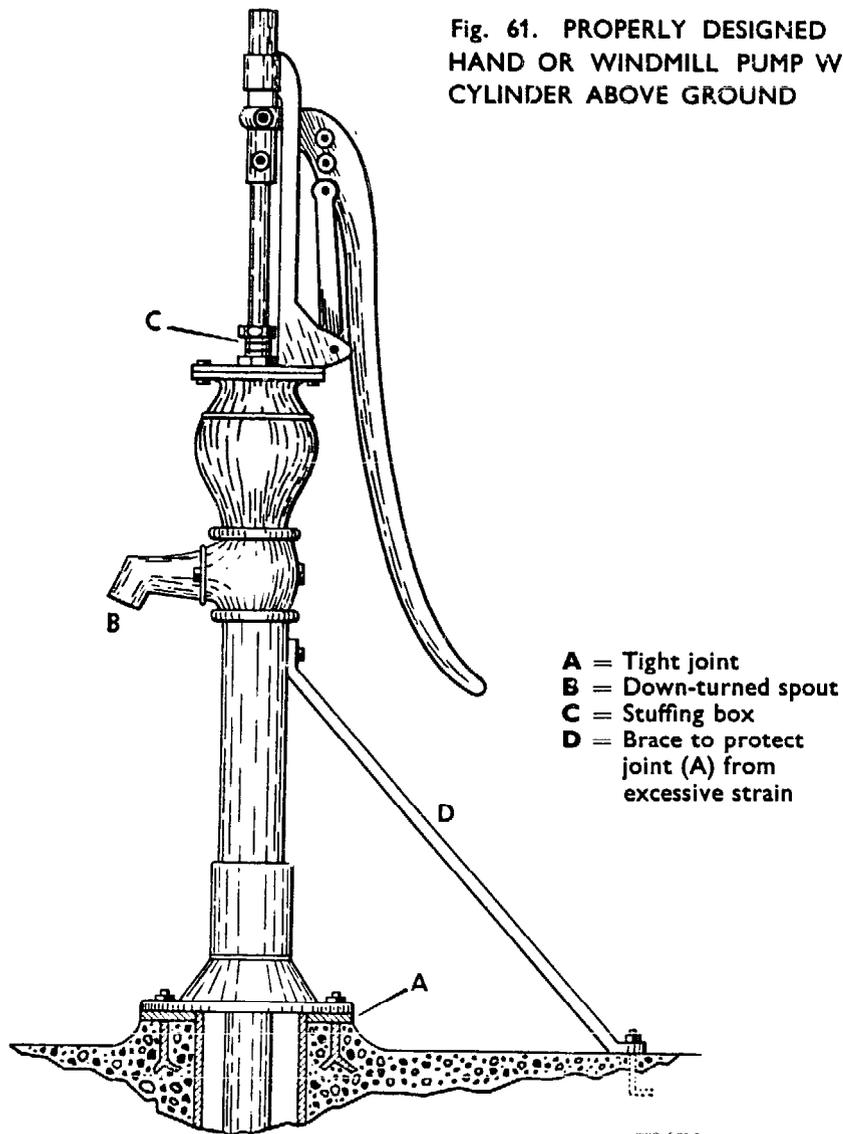
All modern mills are designed in such a manner as to ensure that the windwheels will pivot freely and answer quickly to changes in the direction of the wind. They are also equipped with a " pull-out " system which will automatically turn the windwheel off to one side when the velocity of the wind is excessive—i.e., 48-56 km (30-35 miles) per hour. Provision may be made for lubrication of the mechanism by an oil-pump system operated from the ground.

The size of windmills is usually expressed in terms of the diameters of their windwheels. Sizes of 1.5 m to 9 m (5 ft to 30 ft) may be obtained from manufacturers. An idea of the capacities of windmills may be

Fig. 62. TYPICAL
ARRANGEMENT OF WINDMILL
TOWER, PUMP, AND WELL

WHO 8266
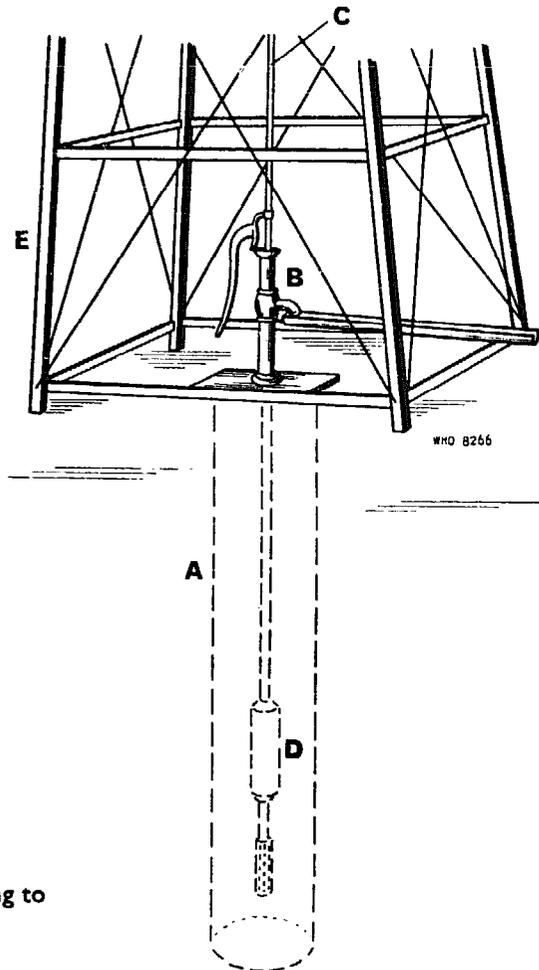
A = Well casing
B = Pump
C = Pump rod extending to
above windmill
D = Pump cylinder
E = Windmill tower

gained from the following examples. A 3-m (10-ft) mill in combination with a reciprocating pump cylinder 7.5 cm (3 in.) in diameter will produce about 760 litres (200 US gal.) of water per hour with a wind velocity of 16 km (10 miles) per hour. The same mill could pump up to 11 350 litres (3000 US gal.) per day, against a total lift of 24 m (80 ft). Similarly, a 7.5-m (25-ft) mill in combination with a 15-cm- (6-in.-) diameter pump cylinder could raise up to 60 560 litres (16 000 US gal.) per day against a head of 37 m (120 ft).

When ordering a windmill, it is important to state the average velocity of the wind, in addition to the data mentioned under "Selection of pumps" (page 151). Windmills will operate with wind velocities as low as 6.4 km (4 miles) per hour. In places where this equipment must be imported from distant manufacturing countries, it is well to plan for the construction of a strong tower, at least, from local materials and to import the rest.

Sanitary Safeguards for Hand- and Power-pump Installations

Besides the selection of pumping equipment possessing the desirable sanitary safeguards, it is important in water-supply systems for domestic use that the installation of this equipment be made in such a manner as to prevent contamination of the water being pumped. This point is often overlooked in small water-systems; and it is not uncommon, in such installations, to observe that drainage water and waste oil from the pump-room floor find an easy way into the well or reservoir water below. Protective measures should be provided for right at the planning stage and should be incorporated into the engineering plans and specifications to be followed by the construction engineer or contractor.

Among the measures recommended by the US Joint Committee on Rural Sanitation,[37] the following may be cited :

" Hand-pump installations

" ... The pump cylinder should be installed near or below the static water level in the well so that priming will not be necessary ...

" The design (of the installation) should provide for frost protection pump drainage within the well ...

" The installation should be designed to facilitate necessary maintenance and repair, including overhead clearance for removing rods and pipe ...

" The pump base should be designed to serve a twofold purpose : first, to provide a means of supporting the pump on the well cover or casing top; and second, to protect the well opening or casing top from the entrance of contaminating water or other material. The base should be of the solid, one-piece, recessed type, cast integrally with or threaded to the pump column or stand. It should be of sufficient diameter and depth to permit a 6-inch [150-mm] well casing to extend at least 1 inch [25 mm] above the surface upon which the pump base is to rest. Provision should be made for fastening the pump base rigidly to the well cover or casing top to prevent movement. The use of a flanged sleeve imbedded in the concrete well cover or a flange threaded on the top of the casing to form a support for the pump base is recommended. Suitable gaskets should be used to insure tight closure. To insure rigidity and the stability of the pump-base closure, the pump should be suitably braced against movement ...

" The protective closing of the pump head, together with the pollution hazard incident to pump priming, makes it essential that the pump cylinders be so installed that priming will be unnecessary.

" Power-pump installations

" ... The sanitation specifications pertaining to hand-operated pumps are in general equally applicable to power-driven installations.

" The base plate of a power-operated pump placed immediately over the well should preferably be designed to form a watertight seal with the well cover or casing. As in the hand-operated pump, the base should be recessed to permit the casing or pipe sleeve to extend into it at least 1 inch [25 mm] above the foundation upon which the pump base rests. All well casings for power-pump installations should extend at least 6 inches [15 cm] above the pump-room floor or platform slab. In installations where the pump is not installed directly over the well or where an open-type pump base is used, the well casing or pipe sleeve should extend at least 6 inches [15 cm] above the floor of the pump

Fig. 63. TYPICAL PUMP INSTALLATION USING STANDARD TEE AND UNDER-GROUND ARRANGEMENT TO DISCHARGE WATER BELOW FROST LINE
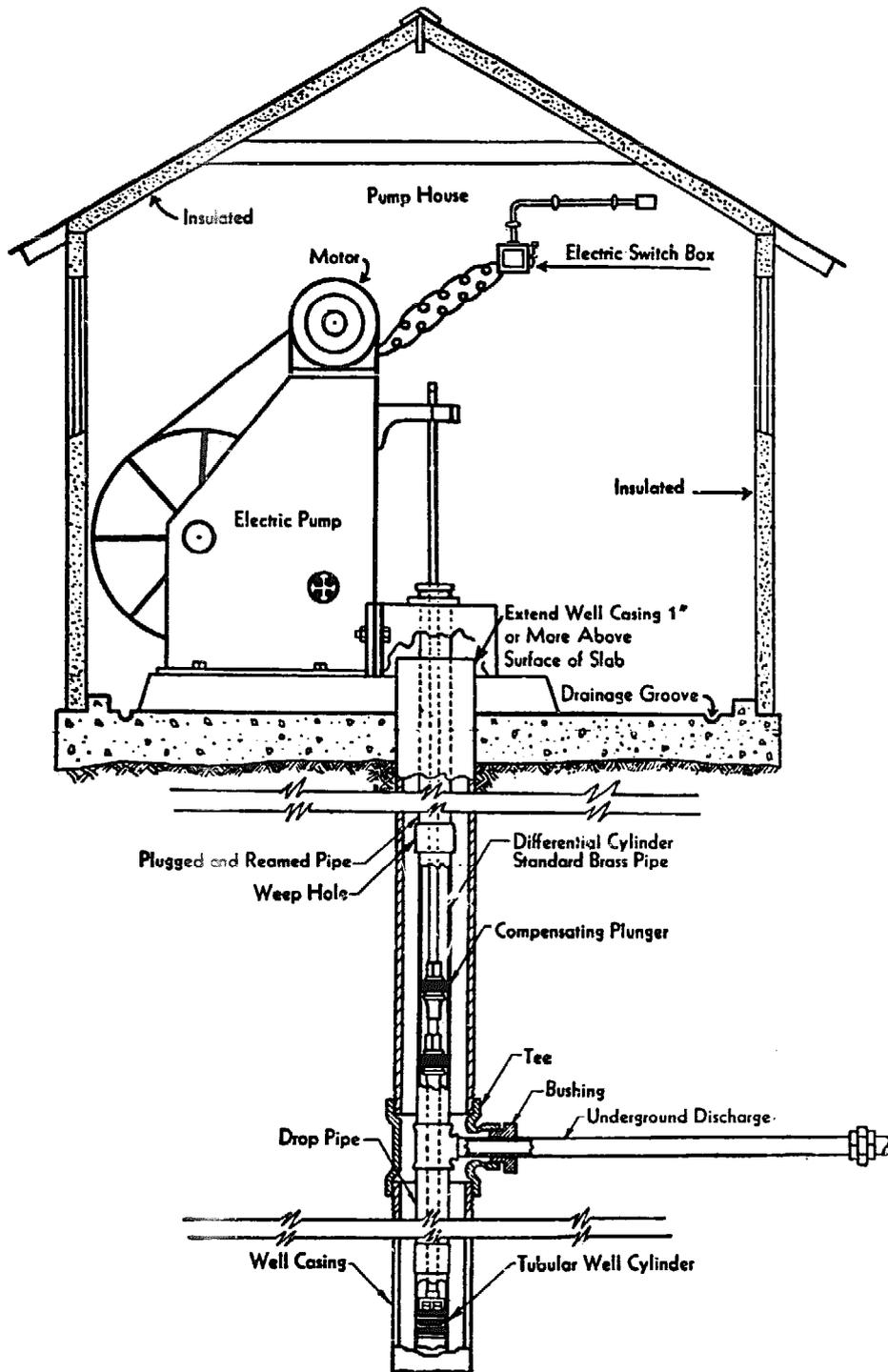
Insulated

Pump House

Motor

Electric Switch Box

Electric Pump

Insulated

Extend Well Casing 1" or More Above Surface of Slab

Drainage Groove

Plugged and Reamed Pipe

Weep Hole

Differential Cylinder Standard Brass Pipe

Compensating Plunger

Tee

Bushing

Underground Discharge

Drop Pipe

Well Casing

Tubular Well Cylinder

Reproduced from US Public Health Service, Joint Committee on Rural Sanitation (1950) *Individual water supply systems*, Washington. p. 47.

house, and the annular space between the casing and the suction pipe should be closed with an acceptable watertight packing or seal.

" Power-pump installations usually require enclosure in some form of protective housing. The pump-room floor should be of watertight construction, preferably concrete, and should slope away in all directions from the well or suction pipe. Due to the protective housing, it should not be necessary to use an underground discharge connection with a power pump. The necessary protection from freezing temperatures can be provided for a motor-operated pump through the installation of a thermostatically controlled electric heater. Automatic frost protection drain-back devices can be designed to drain exposed piping where heating is not practical. For individual installations in rural areas, a 100-watt light bulb may give the needed protection if the pump house is properly constructed and the light wired for continuous burning.

" Where an underground discharge is provided, it can be installed without the use of a pit below the ground surface. Fig. [63] illustrates a method of providing an underground discharge below the frost line. This type of installation is particularly applicable to wells in which the pump cylinder is of larger diameter than the drop pipe.

" Experience with installations of this type indicates that when a pressure tank is provided in the distribution system there is no difficulty with water hammer. Sometimes it may be necessary to provide an air chamber on the discharge line from the well located near the pump.

" If the pumping rate makes the use of an air-relief vent necessary, the open end of the vent should be at least 18 inches [45 cm] above the pump-room floor. The end of the vent pipe should open downward and be protected by proper screening.

" Certain types of power pumps require the filling of the pump system with water for priming or water-lubrication purposes before being started. Water thus returned to the pump should be taken from the original source for which the pump is used through bypass piping in the connected discharge line from the pump to avoid contamination.

" It is desirable to provide a water-sampling cock on the discharge line from power pumps which also may be used for releasing any trapped air in the system. "

For additional notes regarding sanitary specifications for pumping stations, the reader is referred to Annex 9, page 313.

SURFACE WATER

Surface water originates mostly from rainfall and is a mixture of surface run-off and ground water. It includes larges rivers, ponds and lakes, and the small upland streams which may originate from springs and collect the run-off from the watersheds. The quantity of run-off depends upon a large number of factors, the most important of which are the amount and intensity of rainfall, the climate and vegetation and, also, the geological, geographical, and topographical features of the area under consideration. It varies widely, from about 20% in arid and sandy areas where the rainfall is scarce to more than 50% in rocky regions in which the annual rainfall is heavy. Of the remaining portion of the rainfall, some of the water percolates into the ground (see "Ground water", page 57), and the rest is lost by evaporation, transpiration and absorption.

The quality of surface water is governed by its content of living organisms and by the amounts of mineral and organic matter which it may have picked up in the course of its formation. As rain falls through the atmosphere, it collects dust and absorbs oxygen and carbon dioxide from the air. While flowing over the ground, surface water collects silt and particles of organic matter, some of which will ultimately go into solution. It also picks up more carbon dioxide from the vegetation and micro-organisms and bacteria from the topsoil and from decaying matter. On inhabited watersheds, pollution may include faecal material and pathogenic organisms, as well as other human and industrial wastes which have not been properly disposed of. In rural areas, water from small streams draining isolated or uninhabited watersheds may possess adequate bacteriological and chemical quality for human consumption in its natural state. However, in most instances surface water is subject to pollution and contamination by pathogenic organisms and cannot be considered safe without treatment. It should be remembered that clear water is not necessarily fit for human consumption and that one cannot depend wholly on self-purification to produce potable water.

Collection of Rain-water in Cisterns

This system is used by individual families and farms in areas where there is no ground water or where the quality of such water is objectionable for domestic use. Rain-water may also be collected to provide a supply of soft water, for laundry purposes, for example, in places where the avail-

able water is hard, i.e., possessing a high content of mineral salts. The collection of rain-water requires clean roofs, an even roof overhang, collection troughs, and storage tanks. Paved surface may also be used. In Bermuda and the Middle West of the USA, cisterns are commonly employed as a source of domestic water-supply.

The quality of rain-water is affected by the nature and the degree of maintenance of the collecting surfaces. Certain wood or paint materials used on roofs, and dead leaves which usually accumulate in the troughs, are capable of imparting taste and colour to cistern water; rough roof surfaces, such as those made of thatch, are likely to retain wind-blown dust which is later collected by rain-water. Galvanized-iron roofs, which are extensively used in the tropics, provide excellent and smooth surfaces for the collection of rain-water.

To strain out suspended matter, sand filters may be built at the entrance to storage tanks or cisterns. Such filters cannot be depended upon, however, to remove bacteria and to produce safe water. Consequently, cistern water should always be boiled or otherwise disinfected before human consumption.

In the storage tank itself, the chemical as well as bacteriological quality of the rain-water may deteriorate. For example, the mortar employed for the construction of unlined masonry walls may yield substantial amounts of mineral substances to the rain-water. Also, the number of bacteria may considerably increase because of the decomposition of organic matter held in suspension or in solution in the water stored for long periods, or by passage through sand filters which are not properly maintained.

Most of these difficulties can be avoided, however, by suitably constructing and locating the cisterns and by providing for their thorough cleansing at regular intervals. Cisterns should be located in such a manner as to prevent any possibility of pollution of their contents by surface water or by sewage. For this reason they should preferably be sited on higher ground than the surrounding area and higher than, and at least 3 m (10 ft) away from, sewage-disposal installations. For convenience and economy, however, they are frequently built underground. This has the further advantage of keeping the stored water cool in warm climates and of protecting it against freezing in cold regions.

Cisterns may be built of brick or stone masonry, or of reinforced concrete. The latter material is to be preferred, especially for underground cisterns, since it provides watertight walls in addition to necessary structural strength. A concrete mixture of 1 part cement to 2 parts of sand and 3 of gravel, and containing 23 litres (6 US gal., approximately) of water per bag of Portland cement will be satisfactory in most cases. A well-constructed concrete tank needs no surface treatment to make it suitable for water storage. However, in most cases a coating of silicate of soda or bituminous paint is recommended. Masonry walls should

be carefully built with strong cement mortar joints, and the interior surfaces should receive two 1.3-cm (½-in.) plaster coats of 1 : 3 (cement : sand) mortar to provide for waterproofing. Manhole openings should have edges which project about 10 cm (4 in.) above the level of the surrounding surface, and their covers should be tight to prevent the entrance of light, dust, and other pollutional material. An overflow or air-vent provided with screen should be installed. The outlet should be located slightly above the bottom of the tank, and a clean-out pipe flush with the bottom and provided with a drain valve should be installed. Fig. 64 shows typical designs of filters and cisterns.

The amount of rain-water which can be collected in cisterns depends upon the average annual rainfall and the available collecting area (either roofs or watersheds). Theoretically, 2.5 cm (1 in.) of rainfall over 9.3 m² (100 sq. ft) of horizontal surface will yield 236 litres (62 US gal.) of water. Allowing for losses due to evaporation, it may be safely estimated that 190 litres (50 US gal.) will reach the cistern. If, for example, the available roof area is 41.7 m² (450 sq. ft) and the average annual rainfall is 71 cm (28 in.), the amount of rain-water which can be collected is equal to

$$50 \times 28 \times \frac{450}{100} = 6300 \text{ US gal. (23 850 litres) per year.}$$

The size of cistern to be built will depend on the amount of water needed, the amount and distribution of the rainfall, and the size of the collecting surface. Capacity in excess of that required for normal rainfall conditions must be provided as a factor of safety for the abnormally dry year.

The collection of rain-water in cisterns is not as widely practised as its advantages warrant, because the expense involved often makes this system unattractive as a solution for individual homes in rural communities with a relatively low standard of living. In the construction of such systems, precautions must be taken to prevent water from standing in the collection troughs (or roof gutters) and serving as a breeding-place for a variety of nuisance mosquitos and for *Aëdes aegypti*, the mosquito vector of yellow fever in many areas of the world. Such conditions may be avoided by keeping the drains in good repair and by giving them diagonal slope towards the cistern. Frequent inspections will also be required to clear them of accumulating leaves which may block their outlets.

Drainage Basins and Catchment-Areas

Rock and soil catchment-areas

Rock and soil catchment-areas are sometimes used like roofs to collect rain-water which is led into storage tanks by means of suitable placed trenches or drainage pipes. In some regions where rainfall is extremely scarce, such as are found in southern and western Australia, bare granite

Fig. 64. CISTERN WITH SAND FILTER (PUMP INSTALLATION OPTIONAL)
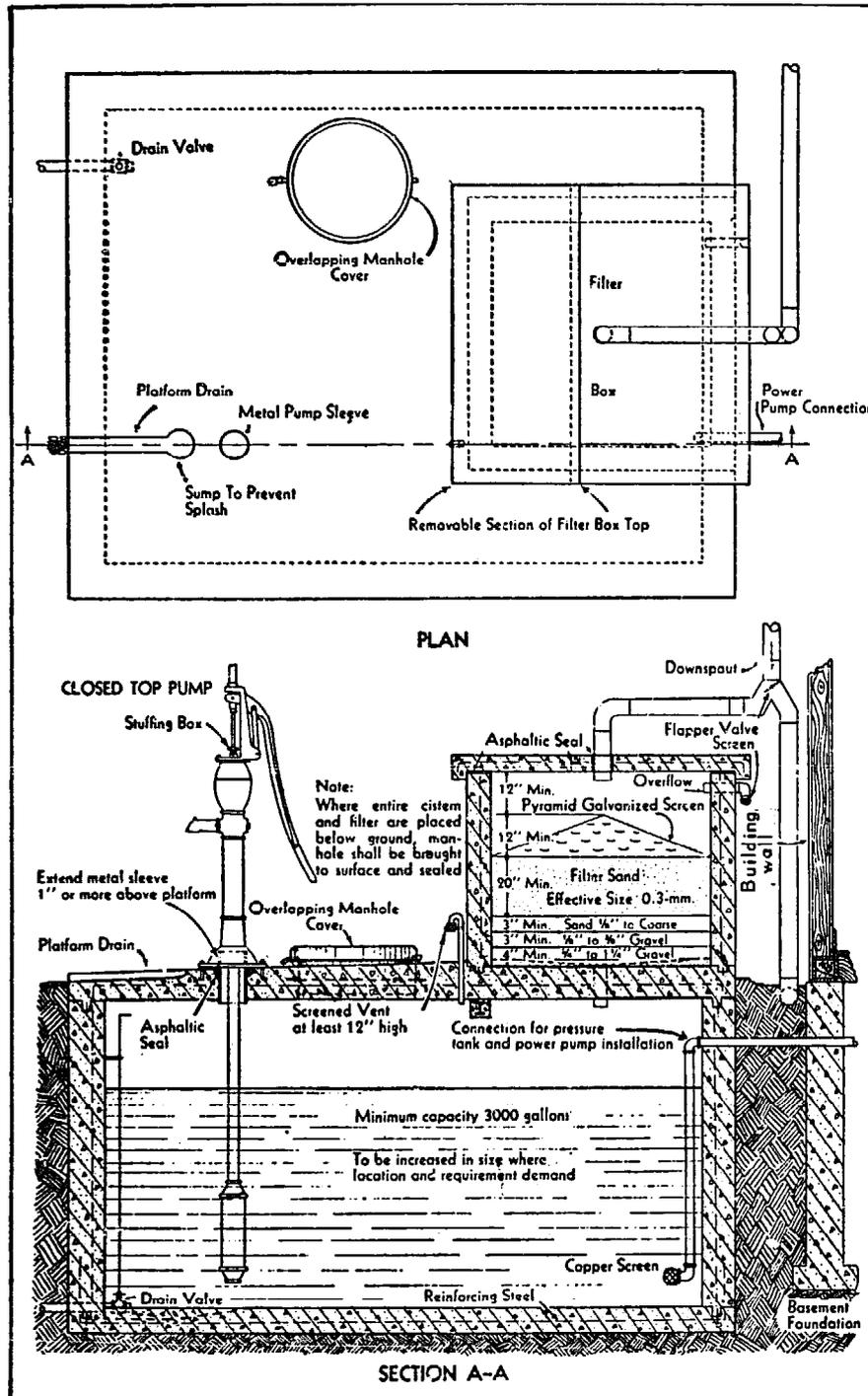
PLAN

SECTION A-A

outcrops are efficiently used for this purpose. Water gathered in this manner serves mainly for irrigation and stock-watering; but, if given adequate treatment and disinfection, it may also be used for domestic consumption. In the latter case, the quality of the water should be adequately protected by taking certain measures such as the provision of a fence around the area, designed to prevent pollution of the watershed by both humans and animals. In the case of soil catchment-surfaces, measures should also be taken against erosion, by the use of vegetative covering, for example, to reduce the turbidity of the water.

Ponds and reservoirs

Ponds and reservoirs may provide an abundant supply of water for use in rural as well as urban areas. Surface water from a small upland stream or spring can sometimes be accumulated in a location suitable from the topographical and geological standpoints. Such an area should possess a saucer shape, and the soil should be able to hold water. The nature of the soil can be determined by means of borings or test holes. Heavy clay soils, silt clays, and clay loams are among the best formations for holding water. The presence of porous layers near the ground surface or of faulty rocks should be carefully investigated by a competent geologist.

The quality of water from ponds and reservoirs may be such as to require little treatment, provided certain sanitary precautions are carefully observed. These include strict measures to protect the watershed of inflowing streams from human and animal pollution and from erosion, and to exclude livestock, campers, and swimmers from the watershed and reservoir area by fencing it. Also, measures should be taken at the time of construction to clear the submerged area of all vegetation and decaying mattter and to provide ample water-storage capacity and area for the deposition of silt and the reduction of bacteria content through the usual agents of self-purification. Depending on the area, the possibility of creating suitable breeding-places in such ponds and open reservoirs for both nuisance and disease-carrying mosquitos and for bilharziasis-carrying snails should be kept in mind. Schemes of this sort should not be undertaken without previous clearance with local health authorities.

In designing the capacity of such reservoirs, ample provision should be made for losses of water by evaporation and by leakage. Depending upon the air temperature and humidity and the wind velocity in the area concerned, annual losses by evaporation alone may be as high as 178 cm (70 in.). Provision should also be made for de-silting facilities through periodic flushing of the reservoirs. It is recommended that the depth of water in a small reservoir at the deeper end should be not less than 1.8 m (6 ft).

Attention must be given to riparian rights, to the probable need to acquire both submerged and surrounding lands, and to other legal problems which may result from impoundment.

Small dams

When a dam is required to impound reservoir water, the most suitable location for such a reservoir will be one that will hold the maximum amount of water with the smallest dam. Sometimes the construction of a low dam, i.e., a dam whose spillway crest is less than 9 m (30 ft) above the natural stream channel, is sufficient to provide enough water-storage capacity for all uses, agricultural as well as domestic, and to permit delivery of water by gravity at the same time. However, the determination of the dam site requires, even for a small earth structure, considerable topographical and geological studies if failures are to be avoided. Among the most common failures is the inability of the dam or the reservoir site to hold the water, which escapes through porous of fissured formations and through the dam itself. Overtopping of earth dams due to unexpected and heavy run-off is also a frequent cause of failure of small water-storage projects.

The average engineer is rarely equipped and experienced to undertake alone the investigations preliminary to the design of such projects. The collaboration of an engineer competent in this field is required for examining the porosity, texture, and composition of the rock formations; for assisting in the determination of the best location and the most suitable type of dam for the foundations available; and, finally, for selecting the earth materials which will go into the construction of an earth dam, if it is decided to build this particular type of structure.

The selection of the type of dam required depends upon a variety of engineering factors; and, in most instances, preliminary designs and estimates must be made for several types before the most economical structure can be decided on. The following types are considered applicable for dams up to 9 m (30 ft) in height:[40] (1) earth embankment, (2) rock fill, (3) solid gravity, (4) arched masonry, (5) hollow gravity or buttress, and (6) timber.

The design and construction of dams, large or small, is a highly specialized task which should not be undertaken lightly by unqualified personnel. If competent consultation is not available, instructions and specifications obtainable from recent literature [12, 17, 40] on the subject should be carefully studied and applied by the construction engineer. Some of the practical problems encountered in the construction of small dams are described in Annex 7, page 297.

Rivers

For small water-supply systems, the use of river water should be avoided as much as possible because of the necessity for thorough treatment and disinfection in order to make such water fit for human consumption. River water may be easily contaminated by disease-carriers and by human and animal wastes; and its quality should always be questioned since, under most rural conditions, it is virtually impossible to observe complete sanitary

control over the entire watershed. Furthermore, self-purification processes cannot be depended upon to make river water bacteriologically safe. Whenever possible, river intakes should be built upstream of inhabited communities.

The intake may consist of a submerged pipeline used with a submerged crib or a screened bellmouth at the open end. It should be placed well below the water surface since the water is cooler at a greater depth and, also, because of ice formation in cold climates; but it should not be close to the river bottom, in order to avoid sediment and suspended matter moving along there. The intake should also be located some distance from the shore and should be large enough for entrance velocities to be kept to a minimum, preferably less than 15 cm (6 in.) per second. Fig. 65 shows a simple intake structure for small water-supply systems from rivers or lakes.

Fig. 65. SMALL INTAKE STRUCTURE
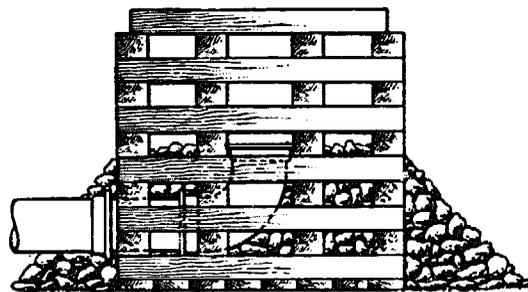
Reproduced from Hardenbergh, W. A. (1952) *Water supply and purification*, p. 52, by kind permission of International Textbook Co., Scranton, Pa., USA

Intakes from small streams frequently require the construction of small diversion dams. In this manner provision can be made for a sufficient depth of water at all times above the intake pipe; for the settling of suspended matter, thereby reducing the turbidity of the water; and for keeping floating leaves and other debris from obstructing the intake structures. Depending upon circumstances such as the depth of water in the river, location, and degree of permanency of the structure, a floating intake made of empty oil drums held in place by a suitable frame and supporting a flexible inlet hose may be used. Intakes should always be designed to function with a minimum of attendance.

The amount of water which can be obtained from a small stream without the construction of a storage reservoir is governed by the rate of minimum flow both per day and per year. The flow of a small stream, i.e., a stream less than 61 cm (2 ft) deep and not more than 15 m (50 ft) wide, may be measured by means of the rectangular weir shown in Annex 3, page 260.[41] With such a device, daily or weekly observations may be made of the flow

over the year. These data may be correlated with the records of rainfall
collected simultaneously. It may be difficult to set a dam across the larger
stream and to prevent leakage around its edges. But, in many instances,
great accuracy is not required. The following formula may be used for
computing the discharge :

$$Q = 3.33 \, b \, H^{3/2} \quad \text{where}$$

Q = discharge, in cubic feet per second,
b = length of weir, in feet, and
H = head over crest of weir, in feet.

Approximate results may be obtained from the table given in the annex
mentioned above.

For smaller streams, the flow may be measured by means of a V-notch
weir of the type shown in Annex 3, and the discharge may be obtained from
the accompanying table. Daily or weekly measurements should be made
over at least one year in order to gather a fair knowledge of the variations
of flow in the stream.

For large rivers, it is necessary to measure at a fixed station the cross-
section of the stream and its mean velocity by floats or current meters
in order to calculate the discharge. These measurements are beyond the
scope of this work, being generally connected with large hydraulic projects.

Pipelines

Once an adequate source of water supply has been secured, provision
must be made to transport the water directly to the village or individual
farm, to a distribution reservoir, or to a treatment plant, as the case may be.
Covered aqueducts and pipelines, especially the latter, are used for con-
veying water which is to be used for domestic consumption. Pipelines are
usually selected because of the ease in transporting and laying pipes in areas
hardly accessible, and because of their efficiency in carrying water. Also,
pipes are not likely to impart taste, odour, or colour to the water being
conveyed, as is sometimes the case with aqueducts.

For rural communities, small pipe sizes are usually required. Wrought
iron, black or galvanized, cast iron, steel, or asbestos-cement are excellent
materials for pipes of 15-cm (6 in.) diameter or less. Galvanized, cast-
iron, or asbestos-cement pipes are to be preferred because of longer life
and the added protection against corrosion. In order to adapt wrought-
iron pipes to different pressures, they are made available in three categories :
(1) standard, (2) extra strong (heavy), and (3) double extra strong (extra
heavy). It should be mentioned that, for the three grades, the outside
diameters of the pipes remain the same while the thickness is increased,
thereby reducing the inside diameter. These pipes have threaded joints.

For sizes larger than 10 cm (4 in.), cast-iron and asbestos-cement pipes are used because of their durability and freedom from corrosion. Steel and reinforced-concrete pipes may be selected for large water-supply projects involving pipes of more than 30-cm (12-in.) diameter.

Certain steps must be observed when designing and constructing pipelines. First, a topographic map should be prepared showing the location of the pipeline and other relevant structures and the profile of the ground along the route to be followed. As the design progresses, pipe sizes and the location of valves and other fittings should also be shown. A pipeline usually follows the profile of the ground; however, its location should be such as to reduce construction costs and internal pressures. Water pressure is reduced when the pipeline is close to the hydraulic grade line (Fig. 66). Of course, the pipeline should not rise above the hydraulic grade line at any point since this would create siphonage and a negative pressure in the pipe. Excessive pressures can be avoided by suitably located overflows or auxiliary reservoirs. The pipes should be laid on gradients which are as uniform as possible. When this is not possible, blow-off valves should be installed at low points to drain the line and remove sediment; and air-relief valves should be placed at summits to allow air to escape when filling the pipe and to prevent interference with the flow of water due to accumulation of air at such points. The velocity of water in the pipe should not be less than 0.60-0.75 m (2-2½ ft) per second in order to prevent the deposit of silt.

Fig. 66. PROFILE OF PIPELINE FROM SOURCE TO DISTRIBUTION SYSTEM *
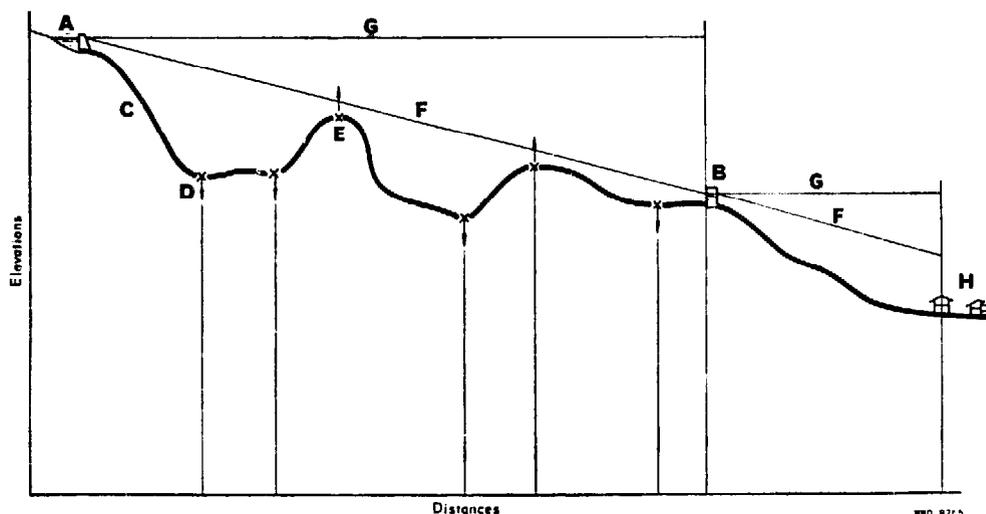
* Not to scale

A = Intake structure   C = Pipeline   F = Hydraulic gradient
    (reservoir, pond, etc.)   D = Blow-off valves   G = Static head
B = Storage reser.oir   E = Air valves   H = Rural town or village

The pipeline should be laid along the straightest route possible; and changes of direction should be made, as far as possible, by gradual deflection in the pipes' joints. Sharp bends should be avoided, as they cause excessive friction which reduces the carrying capacity of the pipelines. The intake should be located at a distance from the shore so as to minimize the danger of pollution. A strainer should be fitted at the inlet end of the pipe to prevent the entrance of fish and debris. Each section of pipe should be inspected before it is laid. The inspection should aim at discovering cracks and damaged coatings. When laying bell-and-spigot cast-iron pipes, the bells should always be directed upwards. In order to protect the pipe against injury from traffic and from weather conditions, it is buried in the ground at a suitable depth. In cold climates, water pipes should be laid below the frost line, which may be as much as 1.8 m (6 ft) deep. In the tropics an earth cover of at least 30 cm (1 ft) should be provided in order to protect the pipes against great variations of temperature and against traffic injury. The width of excavated trenches varies with the required depth but is usually not less than 30-45 cm (12-18 in.).

The pipes should be laid on firm ground or foundation in order to prevent unequal settlement, which may injure pipe joints. In rocky soils, rocks and stones should be cleared away from the bottom of the trenches for 15 cm (6 in.) beyond the pipes and should be replaced by plain earth, sand, or pea-size gravel.

Newly laid pipelines should undergo hydrostatic tests for at least 24 hours to determine both the location and the amount of leakage. The pipeline should be filled slowly, after flushing it through blow-off valves; and all air should be expelled through air valves. While these tests are carried out, the sections of pipe between joints should be covered, but the joints themselves should remain exposed for inspection. The leakage should not be allowed to be greater than 8 litres per metre (6 qt per foot) of joint per 24 hours under normal operating pressure.

In the course of construction, pipelines become contaminated by dust, loose materials, and the hands of workmen. For this reason, they should be disinfected before they are put into service for domestic use. Chlorine, hypochlorite of lime (bleaching powder), and high-test hypochlorite may be used for this purpose. The dose should be not less than 50 p.p.m. of available chlorine and the time of contact not less than 12 hours. This dose may be obtained by dissolving and applying 72 g of high-test calcium hypochlorite, or 240 g of chlorinated lime, to each cubic metre of water (0.07 oz. of high-test calcium hypochlorite, or 0.2 oz. of chlorinated lime, to each cubic foot of water) used to fill and disinfect the pipeline.

Chapter 6

TREATMENT
UNDER RURAL CONDITIONS

As pointed out earlier, rural water-systems should be designed around the need for safeguarding the quality of the natural water selected. It should be the policy of the responsible control agency to restrict the use of water treatment under rural conditions to only those cases where such treatment is absolutely required and where proper plant operation and maintenance can be secured and supervised. Experience in many parts of the world has shown that, once a water-treatment plant is constructed, there is need for constant vigilance on the part of the plant operators and control agencies if the plant itself is not to become involved in the spread of sudden water-borne epidemics. Both present and past literature abounds with the history of water-borne outbreaks of typhoid fevers, cholera, and epidemic jaundice caused by a breakdown of treatment processes (chlorination, for example) for which inexperienced or unqualified operators were responsible.

The control agency should also oppose vigorously the use of treatment processes which the community concerned can ill afford to procure, to operate, and to maintain with its meagre financial resources. Modern equipment designed to minimize maintenance problems is expensive and requires skill in its operation. On the other hand, other equipment which is less costly needs constant maintenance and repair. This explains in part why a careful study, based on engineering and economic analyses, may have to be made to compare, in doubtful situations, the relative merits of water treatment against those of long pipelines bringing in the untreated water of distant springs, artesian wells, or infiltration galleries. When such studies cannot be made, experience shows that, whenever possible, it is wise to make a large investment in order to eliminate operational and maintenance problems.

Among the factors to be considered are the following :
(1) amount of funds available;
(2) costs of construction related to different designs for the same projects;
(3) calibre of personnel available for operation;
(4) supervisory assistance available for operation;
(5) costs of operation (gas, oil, chemical, personnel);
(6) useful operating life for each proposed design.

As an example, it may be cited here that, in Venezuela in 1947, Wagner found that an expenditure of money for the construction of a 10-cm (4-in.), cast-iron pipe 3-4 km (approximately 2 miles) long was justified to eliminate a well 30 m (100 ft) deep supplying 380 litres (100 US gal.) of water per minute by pumping, in spite of the facts that reasonable pump maintenance could be expected, gasoline and oil were cheap, and communications were fairly good.

There may be instances where special conditions or requirements justify complex measures, Such might be the case of a hospital or local industry for which water treatment must be provided. Then, provision is usually made for operation and maintenance by qualified operators and for quality control by the local health administration.

When the construction of a water-treatment plant has been decided upon, particular attention should be paid to planning its layout in such a way that its capacity may be enlarged without difficulty in the future. In rural areas this recommendation assumes considerable importance because of the usual difficulty of forecasting with any degree of accuracy the growth of small towns and villages. Addressing a WHO seminar for waterworks operators in New Delhi, (India) H. G. Baity, who has had world-wide experience in the design of water-treatment plants, stated : [a]

" Observations all over the world teach important lessons about plant layout and design. An opportunity should never be lost to speak a world of advice and caution on this subject. Incalculable sums have been wasted in all countries by failure to follow sound principles of layout and to construct plants capable of extension. Modern reinforced concrete structures are good for a hundred years or more, but short-sighted engineers often design plants adequate only for the immediate future, and with layouts or site restrictions that make necessary the scrapping of the old plant and building a new one as soon as a greater capacity is called for. In North Carolina every one of the plants of thirty years ago had to be abandoned for such reasons. The loss due to lack of foresight ran into millions of dollars. The same thing will doubtless happen in many places in South-East Asia. The lesson expensively learned should prevent a repetition of the waste and inconvenience. This difficulty can be avoided by observing the following precautions :

" 1. By remembering that most communities will continue to grow for a long time, and by estimating populations and water requirements for the ultimate future.

" 2. By providing plant sites of such location, area and topography that they can accommodate indefinite extensions of plants and their facilities.

" 3. By employing the " unit principle " of design for plants (e.g., matching settling basin and filter units) and arranging them in such manner that extensions can be made indefinitely.

" 4. By providing for hydraulic efficiency of the plants, under present and future conditions, and by making layouts in such fashion that present structures will not be in the way of future ones.

[a] Baity, H. G. (1953) *Experiences in improving water purification practices in the United States.* In: *Proceedings, Seminar for Waterworks Operators,* New Delhi (Document issued by WHO Regional Office for South-East Asia and Government of India, Ministry of Health

" Observance of these principles will produce plants that are not only economical and long-lived, but which are so compactly and logically arranged as to be most easily operable. "

Although the central or provincial administration concerned may have at its disposal the services of qualified engineers for the design and supervision of water-treatment plants, small rural communities should not rely unduly on the availability of the services of such specialists in the day-to-day operation of their plants. This statement depends, of course, upon the nature and scope of the process involved under each particular situation. In countries where health administrations are active, through their sanitary engineering departments, in programmes directed at the control of water quality, short training and refresher courses for waterworks operators are organized periodically with considerable success.

Under the discussion of chemical and physical quality (see page 50), a list of the offending substances which may render water unacceptable to consumers has been given. The only ones for which removal may be considered by means of available processes under rural conditions are : turbidity, colour, iron and manganese, and carbon dioxide. Besides the removal of these impurities, it may be necessary to treat water to render it safe from a bacteriological point of view. This is especially true if a sanitary survey combined with a series of bacteriological analyses should reveal the possibility of contamination by pathogenic organisms. Treatment processes which may be applied include sedimentation, filtration, aeration, and chlorination. There are several ways of accomplishing each of these treatment processes, and a selection should be made after a careful consideration of relevant engineering and local factors.

Plain Sedimentation

Only plain sedimentation will be considered here : the use of chemical to assist the process would not be feasible under rural conditions as it would require expenses and skills which are usually beyond local resources. Plain sedimentation in natural or impounded reservoirs is useful for the removal of gross turbidity and for a reduction in bacteria, especially pathogenic bacteria. It can be effective either alone or in combination with slow sand filtration or chlorination.

Generally, plain sedimentation will have the following effects :

(1) *Reduction in turbidity* : The efficiency of sedimentation in the reduction of turbidity is dependent on the nature of the suspended material and the settling time allowed. Before a decision is reached regarding the use of this treatment process, it is necessary to study the nature and characteristics of the suspended matter in the raw water. Turneaure & Russell [36] give the following data concerning the sedimentation rates of various materials :

	Diameter (mm)	Rate of settlement (ft per hour)
Coarse sand	1.0	1200
	0.5	636
Fine sand	0.25	320
	0.10	96
Silt	0.05	34.8
	0.005	0.46
Fine clay	0.001	0.018
	0.0001	0.00018

It is obvious from this tabulation that the reduction of turbidities caused by fine clay or colloidal matter may take considerable time, unless a chemical coagulant, such as aluminium sulfate, is used in specially designed sedimentation tanks to hasten the settling process. The construction of a reservoir under such conditions would serve no useful purpose. On the other hand, coarse material and silt are likely to be entrained by surface water as a result of watershed erosion after heavy rainfalls or floods, for example. The turbidity caused by such materials may often be quickly and efficiently removed by plain sedimentation in a reservoir of suitable capacity. It is therefore necessary, at the time of field investigations and sanitary surveys, to collect as much information as possible on this aspect of surface water sources. Turbidity measurements at various seasons of the year and under different conditions of stream flow will be of extreme value.

(2) *Reduction in bacteria* : Simple holding of water in a reservoir will reduce the total number of bacteria originally present, because they die off faster than they reproduce. This is especially true of pathogens which do not usually find in water a suitable environment for multiplication. The more adverse the conditions are for bacterial growth, the more rapid will be the reduction in bacterial numbers, in waters with low pH, for example. Turneaure & Russell[36] give the following information regarding reduction in bacteria :

Location	Holding time (days)	Bacterial reduction (%)
London, England	3.3-15	49-97
Covington, Ky (Ohio River), USA	30	93
Cincinnati, Ohio (Ohio River), USA	6	87

Depending on local situations, plain holding and sedimentation might accomplish considerable bacterial reduction. It is important, however, to locate, through a sanitary survey, the possible sources of contamination on the drainage . When such contamination is not of human origin, the health hazard considerably reduced.

(3) *Storage* : Any reservoir or tank constructed for the primary purpose of accomplishing sedimentation provides at the same time for storage.

This is an important consideration. Ample storage helps to guarantee a continuous supply of water, which is a fundamental objective. The sedimentation reservoir can therefore serve a double purpose.

(4) *Colour reduction*: Short periods of plain sedimentation are not very effective in reducing colour. Very little specific information is available regarding this matter. Turneaure & Russell [36] report a reduction of from 30% to 70% in Massachusetts reservoirs for storage periods of 2-12 months. This would indicate that only a slow reduction of colour should be expected through this method.

(5) *Production of algae* : Storage of water in an open reservoir provides an opportunity for algae to grow and develop. This may become a more serious problem than the one the reservoir was designed to solve. Algae grow on nutrients such as soluble nitrogen, phosphorus, potash, and some other compounds found in surface water. The greater the quantity of these materials, the larger will be the growth of algae. A small amount of nutrient, however, is enough to support some growth. Usually an indication of the possibility of algae growths can be found by observing other ponds or lakes in the area.

A holding reservoir which stores several days' or weeks' supply of water can be a highly economical and advantageous means of providing both treatment and storage. It should be carefully considered wherever it can be used. In many rural areas simple holding of water will be sufficient treatment to provide a reasonably safe supply. Instead of adding more treatment facilities, the engineer should aim at achieving greater public-health benefit by using available funds to effect a wider distribution of the reservoir's water.

The type of basin most practical for rural areas is that provided by a small and simple earth dam (see page 166). The design of suitable settling tanks, with or without the help of coagulants, requires specialized knowledge, and should be undertaken only by competent water or sanitary engineers.

Slow Sand Filtration

Use and limitations

Slow sand filtration is an excellent method of water treatment for rural water-supplies. It can give good results and requires a minimum of operational and maintenance skill. The turbidity of the raw water to be treated, however, must not exceed definite limits.

Used with the loadings given in the succeeding paragraph, the filter can be expected :

(1) to reduce bacterial counts by 85%-99%, depending on the initial count;

(2) to reduce turbidity from about 50 p.p.m. (the maximum permissible) to 5 p.p.m.;

(3) to reduce colour to a certain extent, depending on the size of sand grains and the rate of filtration.

The slow sand filter is most practical in treatment of water under the following conditions :

(1) gravity system of water supply;

(2) raw water of reasonably good quality bacteriologically but subject to possible contamination;

(3) water generally low in turbidity.

Under other conditions, especially long periods of high turbidity, some preliminary sedimentation will usually be required to prepare the raw

TABLE VII. SLOW SAND FILTER DRAINS : HAZEN'S TABLE *

Filtration rate (m³/m²/day)	Loss of head in sand (m)	Permissible loss of head in under-drain system (m/m)	Approximate relationship between the filter area and cross section of manifold	Approximate velocity in manifold (m/second)	Approximate velocity in laterals (m/second)
2.8	0.028	0.007	6300	0.20	0.12
3.75	0.037	0.009	5600	0.24	0.15
4.70	0.046	0.011	5100	0.27	0.17
5.60	0.055	0.014	4700	0.30	0.19
7.50	0.073	0.018	4200	0.36	0.22
9.35	0.091	0.023	3800	0.41	0.25
14.00	0.137	0.034	3200	0.51	0.32

Size of drains			Maximum area drained (m²)						
		2.80	3.75	4.70	5.60	7.50	9.35	14.00
	cm	in.							
Lateral	5	2	7.4	6.5	6.0	5.5	4.9	4.5	3.8
	8	3	16.8	14.9	13.7	12.8	11.4	10.6	8.7
	10	4	30.1	26.8	24.6	22.8	20.3	18.6	15.6
	13	5	48.2	42.8	39.1	36.3	32.0	29.4	24.8
	15	6	69.7	62.3	56.8	53.0	46.5	42.8	36.2
	20	8	125.0	112.0	102.0	94.0	84.0	76.0	64.0
Manifold	25	10	320	280	250	230	205	185	160
	30	12	455	400	360	335	300	270	220
	38	15	720	640	575	540	475	430	360
	46	18	1040	930	840	770	690	620	520
	53	21	1420	1260	1145	1060	930	850	710
	61	24	1860	1650	1500	1390	1230	1120	930
	69	27	2360	2080	1890	1750	1540	1405	1120
	76	30	2930	2580	2355	2180	1925	1750	1460
	84	33	3520	3160	2880	2600	2300	2140	1770
	91	36	4190	3720	3440	3160	2800	2500	2050

Friction coefficient C = 110 in calculating manifold

Friction coefficient C = 100 in calculating laterals

* Metric adaptation by Professor Azevedo Netto, Mackenzie College, São Paulo, Brazil

water for filtration. For bacteriological control of the filtered water, chlorine may be used.

Design

(1) Raw water : turbidity less than 50 p.p.m. for the water applied to the filter; higher turbidities can be filtered for short periods. Average turbidity should be less than 30 p.p.m. for economical and continuous operation.

(2) Filter loadings : about 2.8 m³/m²/day (3 million US gal./acre/day) or less, depending on the water, filter sand, and desired end-product. The lower the rate of filtration, the more effective will be the treatment (see Table VII).

(3) Filter sand : should be uniform, with a uniformity co-efficient of about 2.00 and never greater than 2.50, and free of organic matter. The effective size should be 0.3-0.4 mm. The finer the filter sand, the more efficient will be its filtering action but the quicker it will clog, thus increasing operation costs. Good results have been obtained with somewhat coarser sand (4-mm) and higher loadings. This reduces the filter sizes and operation cost. With generally clear waters, free of pollution, higher rates are well justified.

(4) Filter bed : about 1.0 m (40 in.) of sand supported on 40 cm (16 in.) of graded, coarse sand and round gravel. The supporting gravel bed should consist of 20 cm (8 in.) of round, washed gravel, from 75 mm (3 in.) to 25 mm (1 in.) in size; 10 cm (4 in.) of round, washed gravel, from 25 mm

Fig. 67.   FILTERED WATER OUTLET
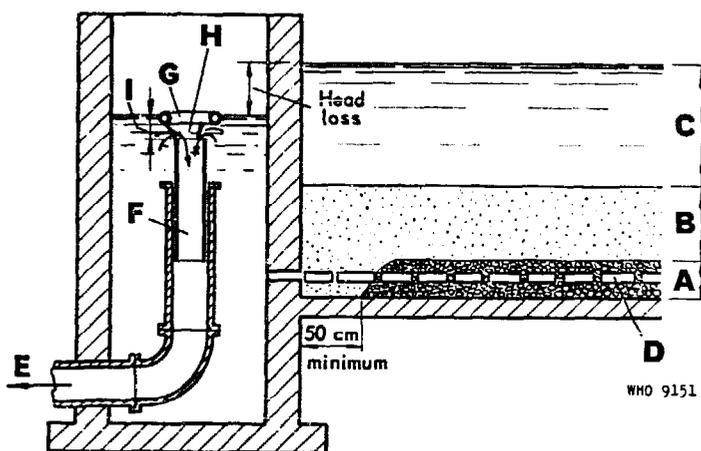
A = Depth of gravel and stone   C = Depth of water over filter bed   F = Telescoping pipe
B = Filter sand   D = Under-drains   G = Float
     E = Filtered water   H = Circular weir
          I = Constant head

Maximum allowable loss of head equals depth of water on filter.

(1 in.) to 10 mm ($^3/_8$ in.) in size; and 10 cm (4 in.) of round, washed 'gravel from 10 mm ($^3/_8$ in.) to 5 mm ($^3/_{16}$ in.) in size. Stone should be kept 50 cm (20 in.) from all sides of the filter. The filter sand will rest on the bottom of the filter around the edges (see Fig. 67). The depth of water on the filter can be from 1.0 m to 1.5 m (40 in. to 60 in.).

(5) Under-drain system : baked clay or concrete pipe, laid with open joints. Pieces 30-40 cm (12-15 in.) long are best for this purpose. The spacing depends on the size of the under-drains and the rate of filtration. Maximum spacing of laterals is 2 m (80 in.). For example, a 5-cm (2-in.) drain tile will drain 7.4 m² (80 sq. ft) at a rate of 2.8 m³/m²/day (3 million US gal./acre/day). At the same rate of filtration, a 7.5-cm (3-in.) tile line will drain 16.8 m² (180 sq. ft) of filter area.

(6) Filtered water outlet : An important feature of a filter is an outlet such as is shown in Fig. 67. This system prevents the possibility of negative pressures and filter damage. When the resistance in the filter due to clogging is equal to the total depth of water on the filter, operation will stop. Obviously, the time to clean the filter is before filtration stops completely. If, however, routine cleaning is not done, this safety outlet will stop the filtration before damage occurs.

(7) Continuous operation : It is important that maximum precautions be taken to assure continuous operation and to maintain the water level above the sand. This is necessary to protect the layer of silt which builds up on the surface of the sand and the slime film which coats the sand grains near the top of the filter, as these deposits help considerably in increasing the efficiency of filtration. If the filter is not operated as indicated above, it may actually provide a favourable breeding-place for bacteria, and the total number of bacteria in the filtered water may be greater than that in the influent.

(8) Filter cleaning : Cleaning is accomplished by very carefully scraping 5-8 cm (2-3 in.) of sand off the top of the filter. This done, the filter is put back into operation. The dirty sand is placed in a washing box for cleaning and re-use. This process can be repeated until about 40% of the sand is removed. At this time the cleaned sand is returned to the filter to the original elevation. The sand must be carefully levelled with light rakes or similar tools in order to make it as smooth as possible.

(9) Sand washing : In rural areas this is mainly a hand job. The sand is agitated in a box with water running through it at a low velocity in order not to wash out the fine particles. As the process goes on, the washing-water clears until the sand is clean. The sand can then be stored and is ready for replacement on the filter.

Note : No rate-control devices are included in such a plant, but a butterfly valve with float arrangement can be used to control the flow onto the filters. This is a simple, inexpensive device which will facilitate operations.

Aeration

What it does

Aeration is useful under certain specific conditions :

(1) *To control tastes and odours* : When tastes and odours are caused by dissolved gases such as hydrogen sulfide, this process is indicated. It can also be effective, perhaps to a lesser degree, when they are caused by decomposing organic matter, chemical wastes, or secretions from micro-organisms. Aeration also increases the oxygen content of natural waters which are not already saturated with it and, in so doing, helps to remove the flat taste of rain-water and distilled water.

(2) *To precipitate iron and manganese* : Iron is more commonly found in natural waters than is manganese. Fortunately, it is easier to remove. A chemical examination of the raw water will reveal the nature of the iron compound(s) in the water. Usually the iron is in the form of ferrous bicarbonate or ferrous sulfate. Upon contact with free oxygen (0.14 p.p.m. O_2 for each p.p.m. of iron oxidized), ferric oxide (Fe_2O_3) will be formed. The reaction takes place at pH 7.0 or over. This compound is insoluble and will settle out. For the latter purpose, a short period of storage and sedimentation, followed, if necessary, by filtration, may be desirable to collect the precipitated iron.

When iron is combined with organic matter, the separation in the presence of organic acids is much more difficult and requires accurate pH control, special filtering materials and equipment, and, sometimes, the addition of other chemicals. Competent advice should be sought if no other water source exists for supplying the area. For large institutions, zeolite equipment specially built for iron removal may be considered.

(3) *To expel carbon dioxide* : Excessive amounts of CO_2 make a water aggressive and dissolve the exposed iron in the water-piping system. Aeration can be useful in the removal of CO_2, which escapes into the air.

Methods of aeration

Under rural conditions it would normally be uneconomical to provide pumping solely for the purpose of aeration. It might be possible, however, to combine the aeration process with pumping from the source to storage. In a gravity system, ample head may be available to provide for aeration.

The water should come into maximum contact with the air so that it becomes saturated with oxygen. The process can be accomplished by letting the water fall over steps as in cascades, by spraying it from nozzles into the air and draining it back into a tank in thin sheets over a concrete apron, or by letting it fall through several perforated trays placed vertically one below the other. Care should be exercised to protect the water

against outside conta nination in the course of aeration and to prevent the access to the aeration structures of insects which may breed in the slime developing on wet surfaces.

In every case, however, preliminary studies with a small, pilot, experimental plant are recommended. In this way a definite idea can be obtained regarding the efficiency of the aeration process under the given sets of circumstances before any large expenditure on construction of aeration structures is made. This is especially important and necessary where experience with this process is limited and where available laboratory facilities are not of the highest calibre.

Corrosion Control

As previously explained, it is rarely possible under rural conditions to achieve by chemical means the scientific control required to prevent corrosion and scale in water containing carbon dioxide and bicarbonate alkalinity. However, the removal of excess carbon dioxide can be accomplished by aeration (as indicated in the previous paragraph) or by causing it to combine with more carbonate, thus reducing the corrosiveness potential of the water. The latter may be attempted by passing the CO_2-laden water through a bed of marble stones or limestone chips. This process is simple and requires no special equipment.

Chlorination

Chlorination has been found to be the most practical method of disinfecting water by chemical means. It kills pathogenic organisms and many other bacteria; but it is not used to sterilize water, which, after all, is not necessary. Chlorine is a very active agent, and will quickly react with organic and inorganic matter present in water. For this reason, enough chlorine must be added to water for disinfection until these reactions have taken place and enough free chlorine is produced (and in some instances chloramines also) for bactericidal purposes. The amount of chlorine so needed, excluding the chlorine residual which may be left after a specified period of disinfection, is the " chlorine demand " of the water.

As already explained, chlorination may be the sole treatment used in small water-supply systems when natural waters are satisfactory from the physical and chemical standpoints, or it may be applied to water which has been clarified through either the sedimentation process or filtration or both. Yet the chlorine demand of such water may vary considerably from time to time, due to dissolved substances which are not removed by the simple processes previously mentioned. It is therefore necessary, in rural as well as urban situations, to check results by means of frequent orthotolidine tests for chlorine residuals and also by means of laboratory tests for coliform bacteria (see page 46). Under rural conditions, dosages

used will usually be rather high; but a residual of 0.5 p.p.m. (mg/litre) after 30 minutes' contact period will be sufficient to achieve ordinary disinfection. (Amoebic cysts may require 2 p.p.m. free residual chlorine after 30 minutes' contact.) Information on household chlorination is given later (see page 186).

Equipment for making the orthotolidine test is simple, compact, and easily transportable. Orthotolidine reagent (1 ml per 100 ml of the water to be tested) gives a yellow colour which indicates the presence of residual chlorine. Colour standards are available as a part of the equipment and permit an exact determination of this residual chlorine. The test is sometimes complicated by high alkalinity or by the presence in the water of iron or nitrites, in which case a false colour is obtained. Where competent supervision or technical advice is available, the necessary modifications may be made to the test.

In most rural areas, chlorine is applied by some simple method rather than by the use of manufactured equipment. This discussion will therefore not include chlorinating equipment, which is commonly employed for the disinfection of urban water-supplies and for emergency purposes, and which requires special skill for its operation and maintenance. This type of equipment is covered thoroughly by many of the references cited in this text.

The most common form of chlorine used is either sodium or calcium hypochlorite, $NaOCl$ or $Ca(OCl)_2$. The available chlorine in these compounds varies from 70% for high-test hypochlorite to 25% or 30% for ordinary bleaching powder. The latter, while more common on the market, is quite unstable and loses strength during storage and when exposed to the air and sunlight.

The batch method of mixing is most commonly used. This involves mixing a predetermined volume to a predetermined strength and applying it to water by means of some gravity system. The strength of the batch should not be more than 0.65% of chlorine by weight, as this is about the limit of solubility of chlorine at ordinary temperatures. As an example, 10 g of ordinary bleaching powder of 25% strength is dissolved in 5 litres of water, giving a stock solution of 500 p.p.m. For disinfection of drinking-water, one part of the stock solution may be added tentatively to 100 parts of the water to be treated. The initial dosage would be 5 p.p.m. If the chlorine residual after 30 minutes' contact were found to be greater than 0.5 p.p.m., the initial dosage could be reduced.

Fig. 68 and 69 show two types of device which may be used to apply stock solutions. The first is a simple but reliable device for discharging a batch-mixed chlorine solution into a tank, open conduit, well, etc. Used together with a water-seal tank and float valve, the solution can be discharged into the suction side of a pump. When the liquid level in the water-seal tank is above the hydraulic gradient, stock solution can be fed into a

Fig. 68.   EQUIPMENT FOR FEEDING HYPOCHLORITE SOLUTION

Flush drain

Water supply

Plan section

Guide

Rubber stopper

Wooden float

Brass tube

Bind rubber tube and brass tube with copper wire

Orifice

3' max.

Brass tube cast in wall

Shut-off valve

Brass flush drain

Thick-wall soft rubber tubing

WHO 9152

Elevation section
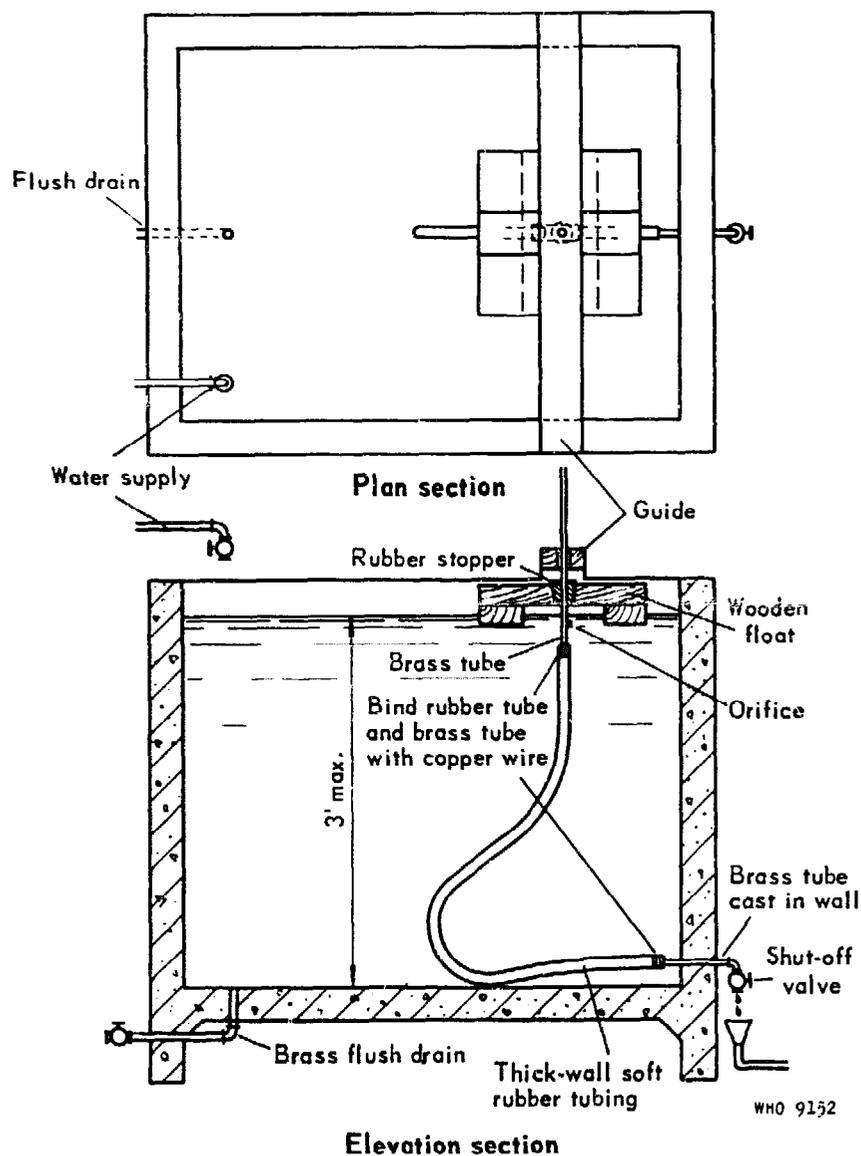
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Note : Brass material may be replaced by plastic.

closed conduit.   The wooden float maintains a constant head at the orifice, which can be large enough to prevent clogging. Fig. 69 shows another simple hypochlorinating device which provides a structure mostly of wood.   When carefully constructed with tanks and barrels lined with asphalt or some

Fig. 69. APPARATUS FOR HYPOCHLORINATION

To point of application of solution
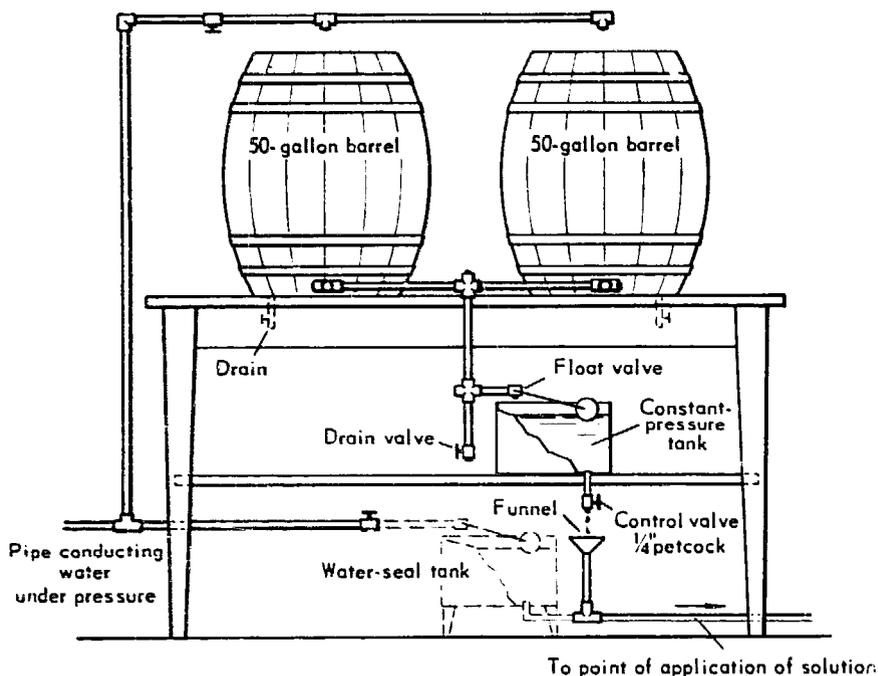
WHO 9153

Water-seal tank and connecting piping are not needed when solution is discharged into open conduit, pump well, etc., but must be used when solution is discharged into suction pipe of pump.

List of Material

2 50-gal. barrels
1 flush tank with float valve
1 flush tank with float valve when needed
   as water seal tank
12 ft or more of 1-in. brass pipe
2 1-in.brass stopcocks
4 1-in. brass "crosses" with 6 plugs
1 1-in. brass tee
1 ¼-in. brass petcock
1 brass reducer to attach petcock to bottom of constant-pressure tank
2 1-in. galvanized iron tees

2 1-in. galvanized iron ells
1 glass or enamel-ware funnel
   Sufficient length of 1-in. galvanized iron pipe to conduct water to barrels and to water seal tank
35 ft of 2 × 4 in. lumber
8 ft of 1 × 6 in. boards
10 ft of 1 × 12 in. boards
16 ft of 1 × 4 in. boards
1-quart graduated measure
1 pair of household scales
1 3-gal. wooden bucket and 1 wooden paddle

(Plastic materials may be used instead of brass.)

corrosion-resistant material, this can be a semi-permanent method of applying stock chlorine solution.

Mechanical equipment is also available on the market for chlorination of individual or community water-supply systems, where chlorine require-

ments are small and supervision is limited. Such equipment is small in size, easily installed and requires little attention. It consists usually of a diaphragm pump for the application of a hypochlorite solution in either a gravity or a pressure supply. The strength of the solution used is preferably around 1% and seldom as much as 5%. Various types of hypochlorinators are available and depend upon whether units are to be electrically or belt driven, automatic or manually operated. Other factors are the type of system and the water pressure available. Most mechanical units make it possible to apply the hypochlorite solution in proportion to the flow of water to be treated. A typical installation consists of a hypochlorinator and its standard accessories, a supply of the disinfecting agent, one or more crock- or rubber-lined solution tanks, and a chlorine residual testing outfit.

When hypochlorinators are ordered, the following data should be furnished to the manufacturers :

If water is pumped :

(1) Sketch of pumping installation
(2) Number and type of pumps
(3) Manual or automatic operation
(4) Pumping rate (litres/second or gallons/minute) and total water pumped per day (cubic metres or gallons)
(5) Electric current available (volts, phase, cycle)
(6) Pressure on pump discharge (minimum and maximum)
(7) Suction lift
(8) Sizes of suction and discharge pipes
(9) Other data (space available for installation, sizes of foot valves, check valves, etc.)

For gravity system :

(1) Sketch of system, indicating source of water supply and distances
(2) Size of main
(3) Size of meter, if any, giving make and description
(4) Pressure at meter or point of installation (minimum and maximum)
(5) Rate of flow (minimum and maximum)
(6) Average daily flow (cubic metres or gallons per day)
(7) Fire flow, if any (litres/second or gallons/minute)
(8) Allowable loss of pressure (m or ft)
(9) Other data (space available for installation, etc.)

Comparison of Treatment Processes

Process	What it accomplishes	Construction cost	Operation cost	Operation attention
Holding reservoir	Turbidity reduction; bacteria reduction	High	Low	Low
Slow sand filter	Turbidity reduction; bacteria reduction	High	Relatively low	Medium
Aeration	Expulsion of gases, iron precipitation	High	Low	Low
Corrosion control	Reduction in corrosiveness	High	Low	Low
Chlorination	Reduction in bacteria	Low	Relatively high	High

Assuming that, under a given set of circumstances, each of the above types of water treatment is properly designed and based on reliable information and that no pumping is involved, the holding reservoir can be the most economical method of obtaining a satisfactory rural water-supply. At the same time, it might well be the most expensive type to construct. On the other hand, if bacterial reduction is the only requirement, simple chlorination would be the cheapest process but would require the most attention and skill from the point of view of operation. This analysis, of course, is an oversimplification of the various difficulties which the engineer actually has to face in the field; but it illustrates the complexity of the problem of water treatment under rural conditions. It is particularly in these difficult situations that the services of a sanitary (public health) engineer are most needed, as he has the knowledge necessary to weigh the advantages and disadvantages of engineering and health factors and to arrive at the best compromise solution under the circumstances.

Household Purification of Water

Because of economic and other reasons, it will not be possible for some time to come to provide satisfactory water-supply installations for millions of rural dwellers in many countries. Yet it remains the duty of public health administrations everywhere to protect the health of rural folk living within their jurisdiction and to instruct those people who have no sanitary water-supplies in methods of rendering water safe to drink. On the basis of experience gathered in many lands, the World Health Organization in 1956 published a paper on the purification of water on a small scale, [11] which is here reproduced by kind permission of its author, Mr R. N. Clark, as it contains detailed, practical instructions which may be used directly both by villagers and by interested health administrations in their health education campaigns in rural areas (see pages 186-192).

There are three general methods for the purification of water on an individual or domestic scale : (*a*) boiling, (*b*) chemical disinfection, and (*c*) filtration.   These three can be used singly or in combination.

Boiling

Boiling is a satisfactory method for destroying disease organisms in water; and it is equally effective whether the water is clear or cloudy, relatively pure or heavily contaminated with organic matter.   Boiling destroys all forms of disease organisms usually encountered in water : bacteria, spores, cercariae, cysts, and ova.

The amount of fuel required to boil water varies with the type of fire, stove, and vessel.   Under the conditions usually associated with the boiling of drinking-water, it requires about 1 kg of wood to boil 1 litre of water (2 lb./qt).

To be safe, water must be brought to a " rolling " boil.   The appearance of bubbles (simmering) is sometimes confused with boiling, as is the appearance of mist or steam over the water.   None of these signs is sufficient indication that water has reached a boiling temperature.   It is good practice to boil water in the same container in which it is to be cooled and stored, and to use this container for no other purpose.

Boiling alters the taste of water because it drives out dissolved gases, particularly carbon dioxide.   The frequent admonition to aerate water by stirring or by pouring from one container into another is badly founded, as it makes for a serious risk of recontamination in handling.   Water left for a period of several hours, up to a day, in a partly filled container, where there is a good air surface exposed, even though the mouth of the container is covered, will lose most of the boiled taste.   In any case, the taste is harmless, and much to be preferred to polluted water.

Chemical disinfection

Chlorine

Chlorine is a useful disinfectant for drinking-water, and is effective against the bacteria commonly associated with water-borne disease.   In the usual doses, it is not effective against certain cysts and ova, nor against organisms embedded in solid particles.   Chlorine enters almost instantaneously into chemical combination with organic matter in water, and in such combined form it is of no use for disinfection.   Sufficient chlorine must therefore be added to satisfy the " chlorine demand " of water in addition to the amount required for bactericidal action.   This combination with other substances may give rise to a chlorine taste, but the presence of such a taste is not a sufficient indication that a free chlorine residual exists. In general, highly polluted water containing large quantities of organic

matter, or cloudy water, is not suited for chlorination. Turbid water can be filtered, and when clear it can be successfully chlorinated.

Chlorine is easiest to apply in the form of a solution. A good stock solution to use in treating water contains about 1% available chlorine, and this is about the strength of antiseptic solutions such as Zonite, Milton Antiseptic, or Javelle water.

Laundry bleaches, available as liquids under a variety of trade names, usually contain about 3%-5% available chlorine, and can be diluted easily to 1%. Dakin's Solution contains about 0.5% available chlorine.

Bleaching powder, or chlorinated lime, is a white powder which contains about 30% available chlorine when freshly made. However, the strength of this powder rapidly vanishes after the can is opened, or in cans that have been stored for a long time. In using chlorinated lime, it is best to use the whole can at once, immediately after opening, in making up a stock solution. The inert lime will settle in a few hours, leaving the active chlorine in the clear solution.

Another type of powder is high-test hypochlorite, which contains about 70% available chlorine. Cans of this powder should be kept as cool as possible; there are instances of cans' bursting when left in the hot sun or in hot storage places. The powder can be used to make a stock solution in the same way as chlorinated lime. High-test hypochlorite is more stable than chlorinated lime, and will keep its strength better after the can is opened, so it is not necessary to use a whole can at once. However, even this material will lose its strength a month or two after a can is opened.

Solutions containing much over 10% available chlorine are unstable in warm climates. Chlorine solutions should be kept in brown or green bottles and stored in dark places.

To make 1 litre of about 1% stock solution, add enough water to make 1 litre (1 quart) to any of the following: either 250 ml (1 cup) of liquid laundry bleach, or 40 g (two-and-a-half tablespoons) of chlorinated lime, or 15 g (one tablespoon) of high-test hypochlorite.

Smaller quantities of stock solution can be made by using proportionate amounts. Zonite or Javelle water can be used without dilution.

To chlorinate water, add three drops of 1% solution to each litre or quart of water or 1 fluid ounce to 32 Imperial gallons. If the water is clear but highly coloured, like very weak tea, or if it has a noticeable sulfur odour, the dosage should be doubled. After dosing, the water should be thoroughly mixed, and left to stand for 20 minutes or longer before being used. Sufficient mixing can be obtained by pouring water from the container in which it is chlorinated into a storage vessel.

Chlorine can be secured in tablet form. Some commercial tablets available are those known as " Halazone ", " Chlor-dechlor ", and " Hydro-chlonazone ". Directions given on the package should be followed carefully. For example, Chlor-dechlor has a double action. This tablet first disinfects

the water with a special chlorine compound, then, after the outer portion of the tablet dissolves, the inner core neutralizes the remaining chlorine to reduce the taste. If more than one tablet is to be used, the whole amount must be put in at one time. Tablets added after the dechlorinating core of even one of these pills is dissolved are completely ineffective.

Iodine

Iodine is a first-class disinfecting agent. Tincture of iodine can be used to disinfect water; normally, two drops of 2% tincture of iodine are sufficient for 1 litre (1 quart) of water. Water which is cloudy or muddy, or water having noticeable colour, even when clear, is not well suited for disinfection with iodine. Turbid water can be filtered, and the clear filtrate can then be treated. If the water is heavily polluted, the dose should be doubled. There is no harm in using such amounts of iodine, but the higher dosage will produce a medicinal taste.

Iodine compounds, such as tetraglycine potassium tri-iodide, have been made into tablets which are effective against amoeba cysts, cercariae, leptospira, and some viruses as well. Some of the commercial names are " Globaline ", " Potable Aqua ", and " Individual Water Purification Tablets ". These tablets appear to be among the most useful disinfecting devices developed to date.

Potassium permanganate

Potassium permanganate, known commonly as " pinkie " or Condy's fluid, has been frequently used for the disinfection of water. It is a powerful oxidizing agent, on which account its action is rapidly spent in waters containing organic material. The commonly used dosage is one part in 2000 or 0.5 g per litre. Potassium permanganate may possibly be effective against the cholera vibrio, but is of little use against other disease organisms. Water treated with potassium permanganate in time produces a dark-brown precipitate, which is noticeable as a coating on glass or porcelain vessels, and which is difficult to remove without scouring. Potassium permanganate is not satisfactory and is not recommended for water disinfection.

Filtration

There are two types of filter commonly used in the treatment of household water supplies : the sand filter, which is relatively coarse, and the ceramic filter, which is of a finer texture.

Sand filter

The household sand filter, unless skilfully operated, is relatively ineffective against bacteria. It will, however, remove cysts, ova, cercariae, and similar relatively large organisms, and will strain out most of the coarse and

visible matter in suspension, although it may pass some fine turbidity or cloudiness. Sand filtration may be made more effective by first carefully treating the water with alum, as a result of which a clear water can be obtained. Some household filters also contain charcoal. Charcoal has no purifying effect, its only function being to absorb certain taste-producing compounds and to make the water " sweeter "; but even this effect is lost unless the charcoal is frequently renewed. Sand filters often get partially clogged with organic matter, and under some conditions this results in bacterial growths in the filter. Reports are common of instances where the filtered water has a higher bacterial content than the unfiltered water. Household sand filters are not recommended unless the water is to be boiled or disinfected after filtration.

With this reservation in mind, the household sand filter fills a definite place in water treatment. It can easily be made for household use wherever fine sand is to be found. The essential points in making a filter are, first, that the depth of sand through which water passes should be at least 60 cm (2 ft)—and an additional 15 cm (6 in.) is desirable—and, second y, that the maximum rate of flow through the filter should not be greater than 2.7 litres per square metre per minute (4 US gallons per square foot per hour).

A simple filter can be constructed from a steel drum 60 cm (24 in.) in diameter and 75 cm (30 in.) high, with the head cut out. Place the drum on a stand, with a container underneath, and drill a hole 2 mm ($^3/_{32}$ in.) in diameter in the bottom of the drum to serve as the filter outlet. Place a few centimetres of small stones, about pea-size, in the bottom of the drum and fill to within 10 cm (4 in.) of the top with rather fine sand. Make a hole in the side of the drum just below the top rim for an overflow, and to it connect a piece of pipe for an overflow line. To operate the filter, keep a continuous flow of water running into the top, just sufficient to keep the filter filled, with a slight overflow. It may be necessary to place a small disc on the surface of the sand under the inlet to avoid a hollow forming in the sand. A filter of these dimensions should deliver one litre per minute (12 gallons per hour) of clear water, suitable for chlorination.

In operating such a filter, it is desirable to keep a continuous flow through the filter at all times. The rate of filtration may fall off in time, but the filter should only be cleaned at long intervals, possibly several weeks or even months, since its efficiency depends on the biological growth on the surface of the sand. Trouble with green growths can be eliminated by covering the filter to keep it perfectly dark, since the green algae depend on light for growth. When it becomes necessary to clean the filter, a very thin layer, about 1/2 cm (1/4 in.) can be scraped off and discarded, following which the surface should be lightly raked or scratched to leave it loose. After several such cleanings, the sand should be restored to its initial level with clean sand after scraping the surface down to a clean level.

Ceramic filters

There are several types of ceramic filter, such as pressure filters, non-pressure filters, and filter pumps; and there is a wide range of ceramic media having different pore sizes. The heart of any of these is the filter candle, and the method of getting water through the candle is only a matter of convenience. Only clean water should be used with ceramic filters; otherwise, with cloudy or turbid water, the candles clog very quickly.

Coarse-grained filter candles are useful in removing suspended matter, helminth ova, cercariae, and cysts. They may be only partially effective in removing the smaller disease organisms, and consequently water should be chlorinated or otherwise disinfected after passage through a coarse-grained or industrial-type filter.

Porcelain filters are made with pore sizes from a maximum pore radius of 50μ or larger down to 0.30μ. To be satisfactory for water purification, the pore radius should be about 1.5μ. Examples of such filters are the Chamberland L_2 and the Selas 015. These and similar fine-grained porcelain filters will remove all disease organisms usually found in drinking-water, and it is quite safe to use water after passage through such a filter without further treatment. Filters and their attachments should be carefully examined at frequent intervals to guard against cracks or leaks which might possibly permit unfiltered water to get by. Porcelain filters must be cleaned and boiled at intervals. If a filter gets coated or clogged, it should be scrubbed under running water with a stiff brush free from soap, grease, or oil, and then boiled for 15 or 20 minutes. Even if the filter does not clog, it should be cleaned and boiled at least once a week.

Another type of filter candle is known as the Kieselguhr or infusorial earth, or diatomaceous earth filter. Like the porcelain, this also is made with various pore sizes. The finer-grained types are efficient in removing all types of bacteria commonly found in water. Among the well-known Kieselguhr filters are the Berkefeld (see Fig. 70) and Mandler filters. Their porosity is graded as V (" viel ", or coarse), N (normal, or intermediate), and W (" wenig ", or fine). The V filters are suitable only for the removal of suspended material; and, after filtration with this type of candle, the water should be further treated to destroy bacteria. The N filters remove the smallest bacteria, and it is safe to use water filtered through this grade without further treatment. The same care should be taken of Kieselguhr candles as of porcelain candles, except that they should be cleaned more frequently, at intervals of not longer than four or five days at the most.

There is a special type of Kieselguhr candle, known as the " Katadyn " filter, in which the surface of the filter is coated with a silver catalyst in such a way that the porosity is not impaired but the bacteria coming in contact with the surface are killed by oligodynamic action. Such a filter needs cleaning only when it becomes clogged.

Filter candles can be mounted in a gravity-type filter, which consists of two reservoirs with the candle or candles attached to the upper. Water is simply poured in at the top, trickles through the ceramic candles, and is stored for use in the lower compartment. Another mounting is made where piped water is available under pressure. The candle is mounted in a pressure case which is attached directly to the water system, filtered water being drawn from the filter as needed. A third type is fitted with a hand pump. The suction tube is put into a vessel of water, and the pump is operated like a bicycle pump, the filter candle being inside. The filtered water is discharged through another tube. Any one of these systems is satisfactory if suitable filter candles are selected.

Fig. 70. BERKEFELD FILTER

Water storage

No matter how much care is used in producing safe water, all the work can be nullified if the water is contaminated after treatment. Boiled or filtered water can be subject to immediate recontamination. Water treated with chlorine or iodine has residual protection which will deal with light recontaminations for a considerable period of time. Even this residual effect disappears in time, however, unless additions of chemical are made. It is very important to keep the water clean.

The principles are simple : use clean vessels to store water; do not dip anything into the water; and keep the vessels covered to prevent the entrance of insects, dust, or other foreign substances.

Cleanliness of the vessel involves periodic emptying, washing, and rinsing with scalding water, or with heavily chlorinated water, to prevent the accumulation of slime growths.

Whenever practicable, small-mouthed vessels should be used, with a neck small enough to prevent the entry of a dipper, cup, or hand. When large vessels are used, arrangements should be made for easy pouring, either by tipping or by rolling the vessel. The best scheme with large vessels is to use a spigot, if possible.
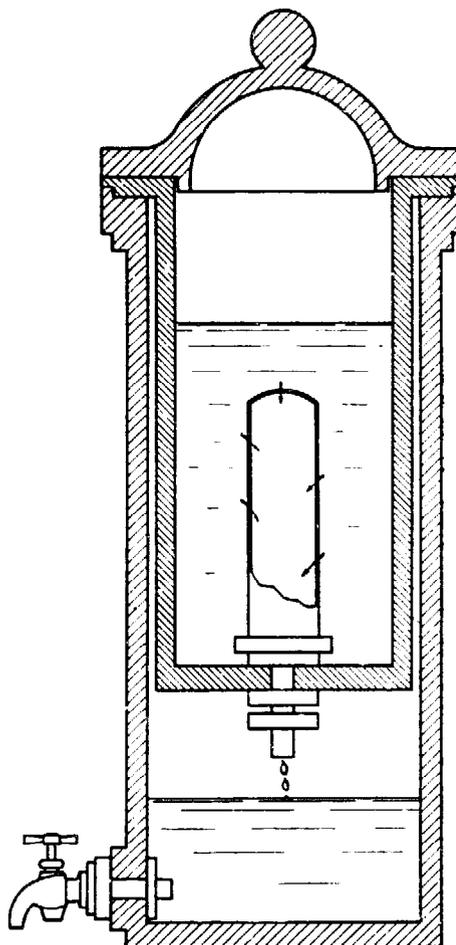
To prevent the entry of dirt and foreign matter, some sort of cover is necessary, preferably of impervious, washable material. The type of cover depends entirely on the vessel. It should be tight enough to keep out flies, wasps, roaches, and other insects, and substantial enough not to be easily lost or broken.

Another point to remember is that ice, too, can harbour contamination. Ice cubes should be made from properly treated water—that is to say, from drinking-water. Unless the ice is reliably known to be pure, it should be used only to pack around beverage containers, never to be put into the beverage itself.

Another precaution relates to the use of bottled water and carbonated beverages. The fact that such products are put into bottles, and capped does not ensure their purity. When water is bottled, its bacterial content decreases with time; but cysts and ova may survive long periods of storage. The amount of sugar in sweetened drinks determines their bactericidal properties, but complete safety depends on initial purity and long storage. In the case of carbonated beverages, the carbon dioxide does inhibit bacteria; but its action is selective, since some organisms are more resistant than others. Carbonation alone cannot be counted on to make a beverage safe. The best policy would seem to be to use only beverages bottled in establishments reliably known to use pure ingredients and to maintain a suitable standard of operation.

Removal of certain objectionable substances

In rural homes where there is running, piped water, it is possible to remove certain objectionable minerals from the domestic supply, when necessary, by using specially built equipment usually available on the market. Household purification equipment may be purchased for the removal of hardness, iron, sulfur, and carbon dioxide and for the control of taste and odour.

Water-softening equipment (Fig. 71) consists of a steel tank containing a bed or a granular synthetic zeolite which has the property of retaining the calcium and magnesium from hard water and of yielding sodium in exchange. Sodium salts do not cause hardness in water. When the zeolite has given up all its sodium content, it must be regenerated with a salt brine, after having been backwashed for the purpose of removing sediment. The calcium and magnesium taken up by the zeolite combine with the chlorine of the salt and form chlorides of calcium and magnesium which are flushed away. At the same time, the sodium of the salt is retained by the zeolite grains; and the bed is again ready for operation. With this equipment it is possible to soften all the house water-supply or, by adequate arrangement of the piping, to treat only the water required for laundry and/or heating purposes, as desired. This equipment can be furnished for either manual

Fig. 71 TYPICAL ZEOLITE WATER-SOFTENER, MANUALLY OPERATED

A = Zeolite
B = Washed and graded gravel
C = Hard-water inlet
D = Soft-water outlet
E = Salt brine
F = Waste pipe
G = Multiport valve
H = Drain plug

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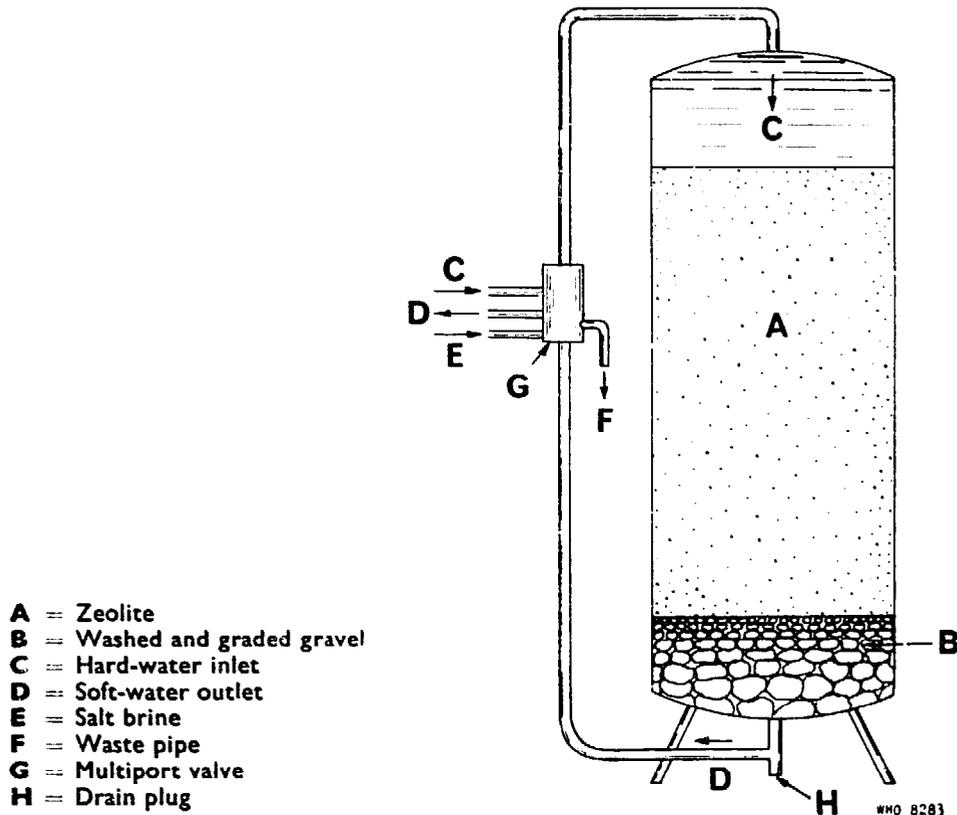
or automatic operation. When ordering, it is necessary to specify the hardness of the water in parts per million, the capacity desired, and the space available.

Similar household equipment is also manufactured for the following purposes :

(1) removal of iron present in water as ferrous bicarbonate, by passing the water through natural greensand zeolites;

(2) removal of carbon dioxide by passing the water through a bed of crushed marble instead of zeolite;

(3) removal of organic compounds causing tastes and odours, by passing the water through a bed of activated charcoal.

Chapter 7

DISTRIBUTION AND USE

In many rural areas, wells equipped with hand pumps and conveniently located are used as sources of domestic water-supply for individual houses and villages. Since the water obtained in this way must be carried in cans or buckets from the wells to the houses, the amount of water is usually limited and too small for the effective promotion of health and personal hygiene. Although the use of wells in villages is inevitable and often dictated by economic and engineering considerations, the distribution of water from a central source by means of pipes to each village house is a goal towards which every community should strive, because of its obvious advantages. The most important benefits are convenience and an increased supply which may be made, at the same time, wholesome and safe for the protection of health.

Water-distribution systems for rural areas are essentially similar to those of urban communities. Often it is possible for the sake of economy to group a number of villages relatively close to each other and to supply them from a central water source. The difference between rural and urban water-distribution systems is to be found in the standards and assumptions upon which engineering designs are based. While not compromising on essential water quality standards, such differences include the amounts of water for domestic consumption, the standards of protection against fire, and the degree of water treatment.

The design of a rural water-distribution system involves : (1) the determination of storage; (2) the location and size of feeders; (3) the location and sizes of distribution pipes, valves, and hydrants; and (4) the determination of the pressure required in the system. Before the design is undertaken, it is necessary to make a reconnaissance survey of the village and of the area leading to the source of supply. Often such a survey, carried out by a trained engineer, will be sufficient to enable him to decide on the route to be followed by the feeder pipe and on the location of distributing reservoirs and main pipes. This reconnaissance should be followed by a topographic survey in order to determine the locations and elevations of street intersections; of all low and high points within the village; of streams, gullies, depressions or similar topographical features which may bear upon the design; and, finally, of the feeder line and the distributing reservoir.

When the construction of the distribution system is completed, similar maps should be prepared for future reference showing the exact location of all pipes, reservoirs, valves, hydrants, and other appurtenances.

Small-Community Distribution Systems

Distributing reservoir

In small distribution systems, whether the water is obtained by gravity or by pumping, it is always desirable to provide a distribution reservoir. The main reasons are :

(1)   the need to satisfy hourly variations in the rate of consumption (in small systems, such variations may be three times the average hourly consumption and sometimes more);

(2)   the desirability of maintaining adequate pressure throughout the distribution system;

(3)   the possibility of repairing adduction pipes between the source of supply and the reservoir, without interruption of the village water service.

(4)   The need to provide for fire protection.

Other advantages which, under certain circumstances, may assume considerable economic importance include the following :

(1)   Where the water is pumped to the reservoir, pumps can be operated uniformly throughout the day.   Such pumps may be much smaller than would be required otherwise.

(2)   With such a reservoir, the size of the adduction pipe between the supply source and the reservoir can be made smaller than would be necessary if the village were fed directly from the water source.

In most small rural schemes no special arrangements are made for fire protection.   Notes on fire services are included on pages 203-205, 206, 239 but the paragraphs preceding these are based on the assumption that no provision for fire hydrants is being made.

The first consideration when designing storage is the capacity which will be provided.   This to a great extent depends on the type of supply, and is influenced by two main factors—the necessity of catering for peak demand periods, and the provision of reserve to cover normal breakdown or maintenance interruptions.

Conditions vary in different parts of the world, but a typical pattern of draw-off in a village is as follows— 30% of the day's supply between 7 a.m. and 8 a.m.; 30% between 5 p.m. and 6.30 p.m.; 35% during the other hours of daylight; and 5% between sunset and sunrise.   Local customs will produce local variations; for instance, in Moslem countries the demand during Ramadan will be high at about 3 a.m., and in other parts of the world where Monday is the traditional " wash-day " the Monday morning

draw-off may be equivalent to the total supply of another day.   These and
similar considerations must be taken into account when assessing the extent
and duration of peak draw-offs : this must then be balanced against the
rate and periods of water delivery.

When water is supplied by gravity from the source it is most economical
in capital cost, as well as most satisfactory from an operational aspect, if
a constant flow is maintained throughout the twenty-four hours.   Obviously
in such a method of working a smaller delivery main is needed than if larger
quantities are required in shorter periods.   When electricity is used for
pumping it is usually most economical to operate for about twenty hours
a day, leaving the pumps idle during the peak hours of electricity demand.
With diesel- or petrol-driven pumps, the cost of attendance (necessarily
continuous with such engines, but normally unnecessary with electric motors)
becomes an important factor, and one shift of eight hours, or two totalling
16 hours, is a frequent method of operation.   It is quite common to find
schemes designed to operate with a single shift of 8 hours initially, increasing
to 16 hours when the demand rises later.   More than 16 hours a day is not
desirable with such engines; not only do labour costs increase but the wear
on machinery working continuously throughout the day and night becomes
excessive and the life of the plant is correspondingly shortened.

Once the probable distribution of draw-off during the 24 hours and the
proposed hours of delivery is decided, two graphs can be drawn, similar
to diagrams A and B in Fig. 72.   In this case a probable demand of 136 000
litres per day is envisaged, to be provided by pumping for eight hours per day
between 8 a.m. and 4 p.m.   These graphs are then superimposed, as at
diagram C, in such a way that the lowest point on line B touches, but does
not come below, line A.   This gives a theoretical picture of how much

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Town requiring 136 000 litres per day, with low draw-off at night and peak periods
7 a.m. to 8 a.m. and 5 p.m. to 6.30 p.m.

Graph A — shows consumption throughout the day; steep slopes show peak hours.

Graph B — shows pumping between 8 a.m. and 4 p.m. 136 000 litres in 8 hours equals
17 000 litres per hour.

Graph C — shows graphs A and B combined.   The vertical distance between the two
lines represents the reservoir capacity required at any time, the maximum distance
occurring at 4 p.m. and representing 102 000 litres required.   Reservoir assumed
to be empty at 8 a.m.

Graph D — shows the effect on reservoir capacity required if pumping hours are changed
to from 5.30 a.m. to 1.30 p.m.   Maximum distance now occurs at 1.30 p.m. and represents
70 000 litres required.   Reservoir empty at 5.30 a.m. and again at 8.00 a.m.

Graph E — shows the same consumption pattern as Graph A but with continuous supply
throughout 24 hours by gravity main at 1250 gals. per hour.   Maximum reservoir
capacity now required at 7 a.m. equals 57 000 litres.   Reservoir empties completely
at 6.30 p.m. and starts refilling immediately as supply exceeds draw-off from that time on.

Fig. 72.   DISTRIBUTION RESERVOIRS: THEORETICAL RESERVOIR CAPACITY REQUIRED
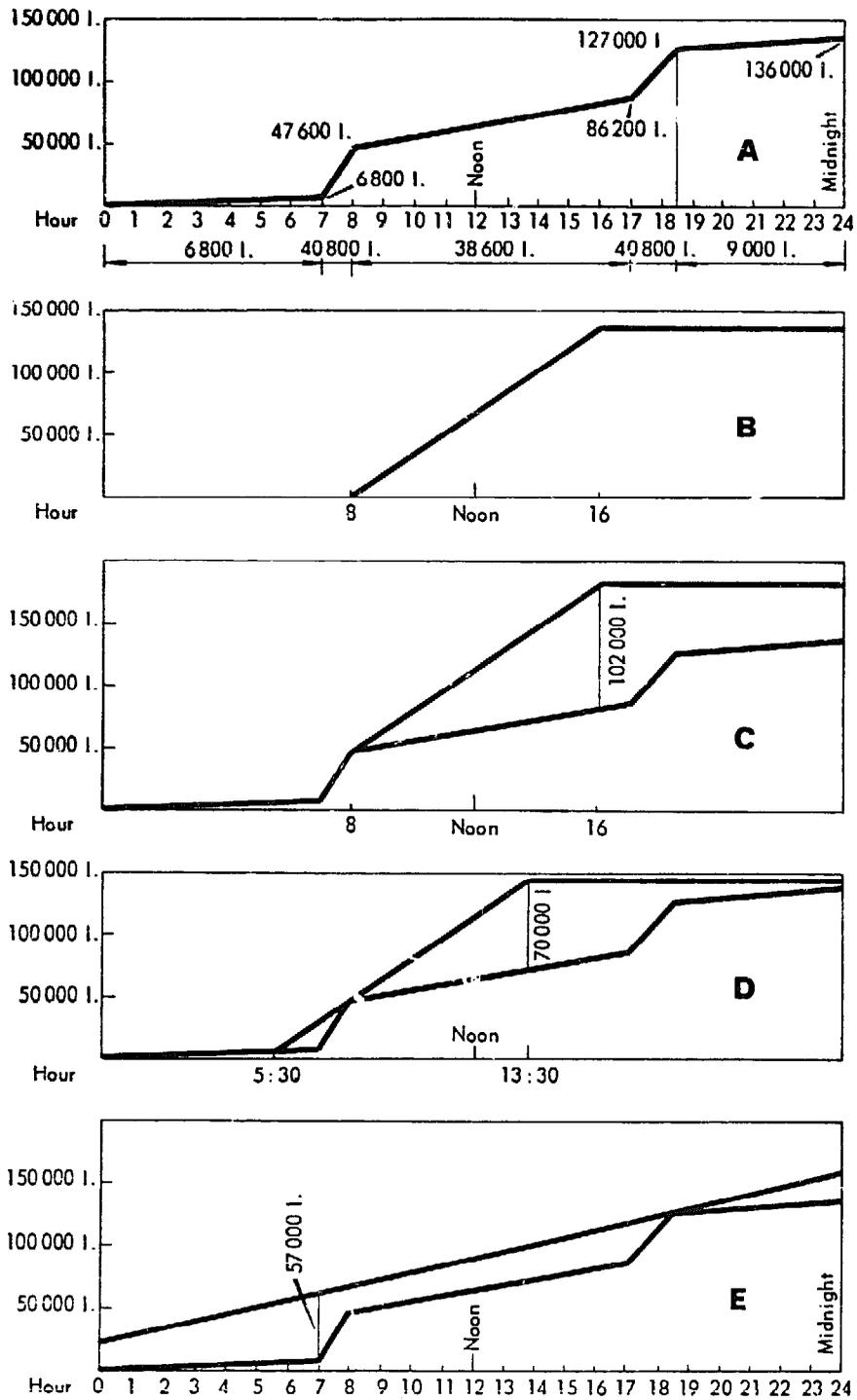
storage will be required, the vertical distance between the two lines representing the amount in the reservoir at any hour of the day.

From this example the reservoir would be empty at 8 a.m., filling to a maximum of 102 000 litres at 4 p.m., and thence emptying at varying rates until 8 a.m. the next day when pumping starts again.

It can be seen that the hours of pumping proposed are uneconomical in this instance, and diagram D shows how the storage required is decreased by arranging the pumping hours between 5.30 a.m. and 1.30 p.m., the maximum difference between supply and demand now being 70 000 litres at 1.30 p.m.

Diagram E assumes that instead of pumping, the water is supplied by a gravity main from source, running through the day and night at 5665 litres per hour. In this case the highest storage demand occurs at 7 a.m., and 57 000 litres' reserve is needed, the reservoir emptying at 6.30 p.m.

The figures obtained by the above method show the minimum storage required to satisfy hourly variation in flow; they take no account of breakdown or repairs, and it is necessary to add to the reservoir capacity for these contingencies. The quantity required for this purpose will depend on the layout of the installation.

Provided that adequate standby pumping plant has been provided and can be brought into use immediately as, for example, if the supply is from duplicate bore-holes each capable of supplying full needs) little need be added for repair purposes, but the problem of a burst main must always be taken into account, and the time taken in repairing such a main must depend on the local facilities available. In a typical rural scheme it is usual to allow 8 hours at the time of day with the highest flow, and to rely on pumping extra hours to make up those lost.

In the instance illustrated, then, an extra 70 800 litres would be provided, assuming that a burst might occur at 7 a.m., and this, added to the requirements calculated from diagram D, would suggest a storage reservoir of 140 800 litres. If the supply were from a gravity main, as in diagram E, the reservoir would be calculated on the basis of 127 800 litres.

It will be seen that in both these instances the storage required is in the neighbourhood of a day's supply, and in cases where conditions are not sufficiently well known for accurate calculations to be made it is usual, as a rule-of-thumb method, to work on one day's supply as the storage required. In no case should such storage be less than half a day's supply.

There are conditions under which much larger storage should be provided, e.g., where pumping is by electricity of which the supply is outside the control of the water authority and which may go out of action for long periods. In such cases it is usual to be pessimistic and to allow for considerable periods of interruption.

Once the size of the reservoir required has been arrived at, the next consideration is its site, and one of the most important points influencing

this choice is the question of levels. It is necessary that the bottom water level shall be at such a height that, allowing for friction loss in the distribution mains, a residual head of about 10 metres (33 feet) for single-storey buildings is obtained in any part of the system. This can be ensured either by siting the reservoir on high ground or by building on a tower. Since the cost of an elevated tank is much more expensive than of one built on the ground. the first choice of site will nearly always be high ground if there is any within a suitable distance from the town.

Assuming, however, that the site is flat and that an elevated tank is required, it is usual to construct this tank in a position which is relatively central to the distribution (thus avoiding long, and consequently large-diameter, service mains), and which has a tendency toward the pumping station rather than away from it so as to keep the friction in the pumping main to a minimum.

Wherever it is possible to avoid it, no distribution mains or connexions should be taken directly from the rising main, and all water should be pumped in the first instance to the tank directly. This is particularly important when centrifugal pumps with steep efficiency curves are used as they can pump at all times at a maximum efficiency if the head does not fluctuate with the demand.

Other advantages of direct pumping are : the ability to close down parts of the distribution system without interfering with the rest of the town, and to check consumption by observing the draw-off from the tank, the increased contact period when chlorine is used as a sterilizing agent, and the maintenance of a much more constant pressure in all services. Leak detection, too, is simpler when individual parts of the system can be shut off or metered separately, as is not possible when pumping is done into the distribution system.

There are, however, occasions when a combined rising and distribution main are desirable, particularly when of necessity the reservoir is at the opposite end of the town from the pumping plant so that for direct pumping a long rising main would have to be laid parallel to a service main, with consequent duplication of costs. With a pump of very flexible performance, such as a reciprocating pump, a saving in fuel results if all the water does not have to be pumped to a high-level reservoir, but is drawn off *en route* at a lower head.

Ground-level reservoirs are usually built of masonry, mass concrete or reinforced concrete according to the materials and local skills available Reinforced concrete is most economical in cement (which is, in most cases, the most expensive of the materials used, particularly in rural areas where long transport hauls are involved) but on the other hand it needs steel, timber for forms, and skilled supervision. Masonry is usually cheaper than mass concrete where suitable stone is available, as the aggregate does not have to be broken and graded to the same extent, and forms are unnecessary,

Fig. 73. GROUND-LEVEL RESERVOIRS

A

Vents

Concrete roof supported
by pillars or walls

Water level

Earth cover

Gravity section
mass concrete
or masonry

Reinforced
concrete
walls

Bitumen
joint

Excavated
material used
for banking at
side and cover
to roof

Concrete
floor

Increased
thickness
of concrete
under walls

B

Concrete roof

Masonry walls
with concrete
filling
(No forms
required)

fillet

Concrete foundation and floor

C

Removable slab
or
Lockable cast-iron cover

Earth cover

6" minimum

Ladder

Concrete roof

Reinforcement

D

d   c

b

a

B

C,D

A

WHO 9155

A = Cross-section of reservoir
B = Types of walls for reservoirs
C = Sketch detail of manhole opening in
reservoir cover

D = Typical valve arrangement for ground-
level reservoir with two compart-
ments
Aa = Effluent
Bb = Supply
Cc = Overflow
Dd = Drain

but it is more difficult to make watertight. A compromise between masonry and mass concrete is often employed, using thin masonry walls and filling between them with concrete. In this case walls are stepped, not battered (see Fig. 73B).

Joints in concrete walls should be avoided as far as possible and are the most usual causes of leakage in reservoirs. Where possible, vertical joints should always have a copper or polythene strip built in. Where this is impossible, and in all horizontal joints such as occur at the end of a day's placing, the surface should be left rough, and when the next layer is added the old surface should be cleaned and painted with cement and water to ensure a good bond.

To prevent leakage in a concrete reservoir, particularly when constant supervision of the work has not been possible and there is a danger that the material has not been adequately tamped during construction, it is as well to paint the whole of the inside surface with a bitumen compound or with a solution of sodium silicate (water-glass). A better (but considerably more expensive) method is to render the interior surface with about a ¾-in. thickness of mortar composed of waterproof cement and sand, after thoroughly roughening the surface to be rendered to ensure a good key.

Elevated tanks may be of reinforced concrete or of steel. When a number of tanks of similar size are to be built in a series of villages, reinforced concrete can be more economical as forms can be re-used, machinery such as hoist, concrete mixer, vibrator, etc., can be transported from site to site, and the same gang of workers can be employed. After a few tanks have been built in this way costs fall as the men employed will become accustomed to the method of construction and their individual duties, but at all times careful supervision must be continuous. For single small tanks it is usually found that steel is a much simpler, and usually cheaper, form of construction. A common form of such a tank is made from pressed steel plates each 4 ft square, which can be bolted together on the top of a tower which is similarly prefabricated and assembled. These tanks are sent out complete by manufacturers with all bolts, washers, jointing compound, ladders, pipework, valves, depth gauges, etc., and the assembly is relatively easy, requiring less supervision than other types of construction; the only local material used is the concrete in the tower foundations.

This form of sectional steel construction is also used on occasion for ground-level tanks on difficult sites, such as on rocky hilltops, and in country where stone suitable for concrete is scarce. In these instances the tanks should be mounted on dwarf walls of concrete or brickwork at such a height above ground level as to allow of access below for inspection and painting regularly.

Covers should be included in the design of all reservoirs. Access to the interior should be through tightly-fitting manhole covers which are suffi-

ciently raised above ground or roof level to prevent surface water from entering. Covers are also needed to prevent the entrance of sunlight which favours the multiplication of algae and other micro-organisms in water. Where there is any possibility of interference by members of the public these manholes should be lockable.

Ventilation has to be provided to allow the air in the reservoir space to escape when water enters, and such ventilators should be designed to prevent surface- or rain-water entering, and to minimise the risk of dust getting into the reservoir; they should be screened with fine mesh wire (not less than 18-mesh) to keep out bats, birds, animals, mosquitos and other insects. Bats are a particular nuisance in overhead tanks; they will enter through very small openings and love the dark, humid atmosphere in the space below the roofs of these tanks.

Small reservoirs and tanks are frequently built as a single unit with a clear space inside, but it is preferable to divide any reservoir other than the very smallest into two sections by means of a vertical wall and to arrange valves and piping in such a way as to allow either section to be used independently. This prevents interruption of the supply during servicing and cleaning, but the wall must be designed to stand the thrust in either direction. When a ground-level tank is built to meet an existing demand which is expected to increase in the future, one wall may be designed of sufficient strength to become a partition wall when the storage capacity is later added to by the building of an extension to the reservoir.

Ground-level tanks may be built on the ground, wholly underground, or partially buried, the choice of design depending largely on the level required. If the ground is hard rock and excavation is expensive, a tank with its base built at about ground level will normally be least expensive; in average ground a common form of construction is to build the tank half below and half above the surface, the excavated material being used to form sloping banks around, and a 6-in. earth cover over, the reservoir.

Every reservoir needs an inlet, outlet, overflow and wash-out. In balancing or " floating " tanks, the inlet and outlet may be combined and a single connexion may serve the dual purpose. This should be either connected through the side of the tank with the inlet of the pipe at least six inches from the bottom of the tank, or brought up through the floor and carried up inside six inches above the floor. Thus there is a " dead " volume of water six inches deep at the bottom of the reservoir which cannot be drawn off through the outlet : this allows for any particles to settle out and to be drawn off at regular intervals through the wash-out pipe, which must be at the lowest point of the tank. In tanks with concrete floors, it is usual to make the floors slope to one point and there construct a sump from which the outlet is taken. In this way cleaning down is facilitated, and it is possible to sweep the floor clean after the normal storage has been reduced to the outlet level, and to disinfect the tank.

When a float valve is used to control the level in the tank, the overflow should never come into action if the valve is working properly. In the case of a "floating" tank it is usual to control the inflow through a float valve and the outlet joins the delivery pipe through a non-return (see Fig. 74 A). A depth gauge operated by a float and wire shows the amount of water within the tank, and is visible from the outside.

Fig. 74. ELEVATED STORAGE TANKS
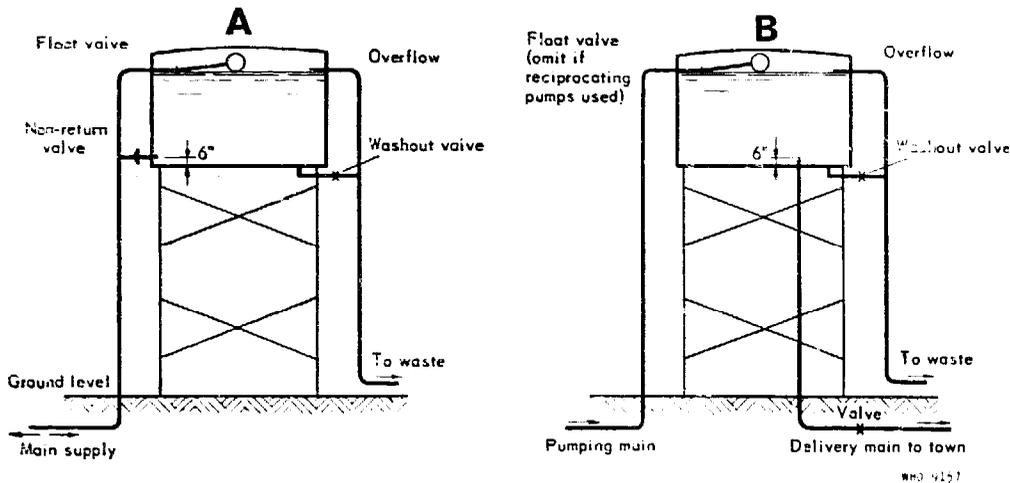
Outlet always taken from 6 in. above tank floor; wash-out at extreme bottom of tank

A = Diagrammatic arrangement of pipes when overhead tank acts as balancer (floating tank). Not suitable for use with reciprocating pumps.

B = Diagrammatic arrangement of pipes when pumping direct to storage tank

When a float valve is not used, there is no control on the depth of water except the intelligence of the operator of the supply pump and the overflow, and carelessness in adjusting the hours of pumping to the draw-off can result in considerable waste, while the farther the tank is from the pump-house the easier it is to overlook such waste. The simple indicator shown in Fig. 75 is one way of reducing this to the minimum as, properly sited, it can be seen for a considerable distance. However, the nearer the tank is to the pump-house the easier this control becomes.

When it is desired to make provision for fire hydrants the needs of fire services must be taken into account in calculating reservoir capacity. Experience shows that, for small communities, the amount of water needed for fire-fighting alone may be several times as great as the daily requirement for domestic consumption.

Very little data are available for determining the amount of water required for fires in small towns and villages. In France water supply reservoirs serving rural communities must carry a minimum of 120 cubic

Fig. 75. WATER-LEVEL INDICATOR FOR ELEVATED STORAGE TANKS
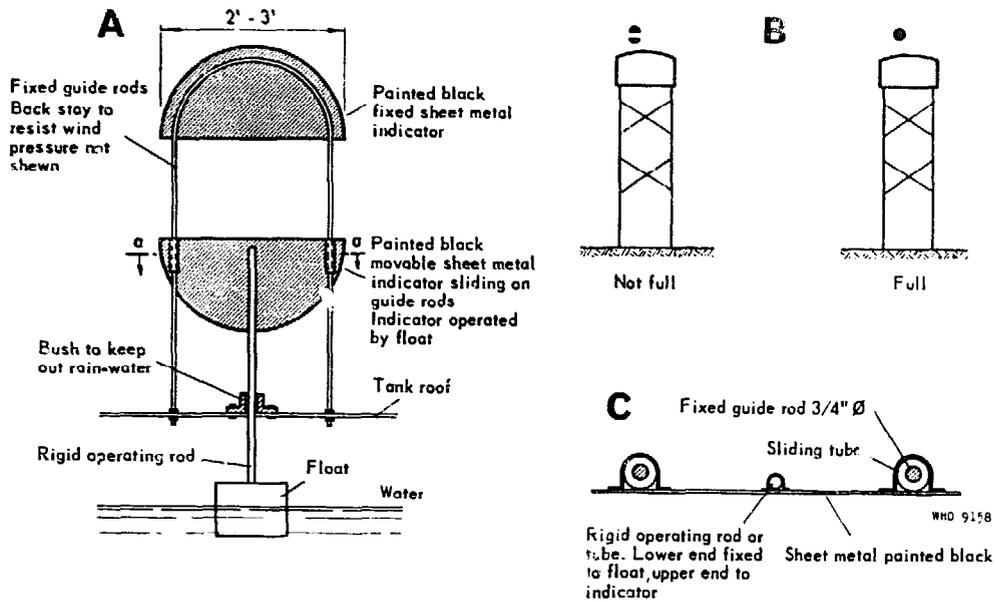
A = Suitable indicator for top two to three feet of water in tank

B = Appearance of indicator from a distance; it should be orientated so that it appears against the skyline

from observation point; it can be seen clearly a mile away.

C = Section at a, showing construction and operation of lower indicator

metres (31 700 US gal.) of water in reserve for fire-fighting purposes. For populations up to 5000 inhabitants, Table VIII shows the fire-flow required in the USA by the National Board of Fire Underwriters (NBFU) and in one country of South America where the problem has received considerable attention.

TABLE VIII. FIRE-FLOW REQUIREMENTS FOR SMALL TOWNS IN THE USA AND IN A SOUTH AMERICAN COUNTRY

Population	Required fire-flow			
	USA		a South American country	
	litres/minute	duration of fire, hours	litres/minute	duration of fire, hours
1 000	3 785	5	*	*
2 000	5 678	5	300	2
4 000	7 570	10	300	2
5 000	8 516	10	300	2

* No provision for fire-flow for populations of less than 2000 inhabitants

This table shows a great discrepancy which is due to the difference in conditions prevailing between rural towns in the USA and those in this particular South American country where rural houses are smaller and of less value, are built on one floor only and at a substantial distance from each other, and, finally, are seldom insured. It also shows that the decision regarding fire-flow requirements must be based on a careful analysis of local conditions. In many rural areas, however, no storage provision is made for fire-fighting and, in cases of fire, other sources of water (if any) are tapped. Under such circumstances there is a danger that the water-supply system may receive a considerable amount of gross pollution through an accidental cross-connexion with the emergency fire piping. In a few towns, there is no storage for this purpose, but the distribution pipes are large enough for water to be pumped directly into them in the event of a fire.

Pipes, pipe accessories and service connexions

Pipes

As stated before (page 168), galvanized wrought-iron, cast-iron, and asbestos-cement pipes are most commonly used in small water-supply and distribution systems for diameters of less than 15 cm (6 in.), cast-iron pipes being preferred for larger sizes. Pipes made of other materials, such as transite pipe composed of a mixture of cement and asbestos fibre, are also available in many countries. For service pipes, galvanized iron is extensively used, although lead, copper, and, more recently, plastic pipes [34] are also laid.

In selecting pipe materials for use in rural water-systems, it is important to pay attention to some of the qualities of the water to be distributed. Since it is most likely that this water will receive no treatment (except disinfection, perhaps) before distribution, the presence of excessive amounts of carbon dioxide and of hardness (bicarbonate of calcium and other salts) should be carefully investigated. Carbon dioxide causes tuberculation of unlined iron pipes, while calcium salts develop incrustation—two conditions which result in substantial loss of carrying capacities in small pipes within a relatively short time. Corrosion also takes place at the contact of iron pipes with certain soils and in iron pipes conveying water which is relatively pure, in the chemical sense of the word. Pipes made of cast iron and asbestos-cement, as well as those provided with an inside coating (galvanized or bituminous linings), resist corrosion and tuberculation and are much used for this reason. Where no provision is made for removal of excessive hardness, the sizes of distribution pipes should be increased.

Valves

In distribution systems, different types of valves are used, each of them for a specific purpose. Gate valves are used for controlling the flow of

water. In principle they should be placed at such points that at times of repair only a small part of the distribution piping needs to be shut off, while the flow of water continues in the rest of the system. However, experience shows that in rural areas valves are seldom operated and, consequently, are soon " frozen " tight and are out of operation. Furthermore, the scope of the distribution grid is usually very limited, and valves are relatively expensive. For these reasons, the use of gate valves should be restricted to important points only and their number kept as small as possible. The location of these points will depend mostly upon the importance of village blocks served and the distribution and scattering of houses within the village. For large distribution systems where provision is made for fire protection, the National Board of Fire Underwriters [39] of the USA recommends that valves should be so located that not more than 150 m (500 ft) of main in the high-value districts nor more than 240 m (800 ft) in the residential areas would have to be shut down because of any single break, accident, or repair to the system. Gate valves are, of course, needed at dead ends and at depressions for the purpose of blowing off sediment from time to time. All valves should be protected by boxes (manholes) and should be easily accessible for operation and replacement.

Check valves allow water to flow in one direction and prevent it from flowing back. They are used on all pipelines leading from pumps in order to prevent water from running back to the pumps when these are stopped.

Air valves allow air to escape from high points in pipelines (see page 169).

Pressure-reducing valves are used to reduce the water pressure in pipes to any desired value.

Meters

Meters are used to measure the volume of water flowing through a pipeline or through a service connexion (service water meters). The use of service water meters in rural water-distribution systems requires a careful decision on the part of the planning engineer because meters demand considerable as well as skilful attention and testing for reliable operation, and also because they are easily thrown out of order by sediment, especially hardness deposition. On the other hand, service water meters may permit the establishment of the most equitable method of water taxation, i.e., the payment for the amount of water actually consumed. Their installation always results in a decrease in water consumption and a reduction of waste in the plumbing systems of houses. The possibility of the water customer's by-passing the meters under conditions of waterworks operation prevailing in most rural areas should not be overlooked, however. These meters are expensive in original cost, and the decision as to their use should be very carefully weighed by the engineer and village council or town authority concerned.

Hydrants

These are built to provide connexions for 6.35-cm (2½-in.) diameter. fire hoses. For small towns and villages, 19-cm (7½-in.) diameter hydrants equipped with two outlets are sufficient. They should be located not more than 91 m (300 ft) apart, preferably at street intersections; and they should be protected against traffic hazards.

Service pipe

The service pipe connects the street distribution pipe to the house's plumbing system or storage tank. In small water-supply schemes, the service pipe will, in most instances, be rigidly connected to the street pipe. It is preferable, however, to insert a " gooseneck " about 60 cm (2 ft) long made of flexible copper or plastic tubing between the corporation cock inserted into the main and the service pipe leading to the house. In this way breakage due to uneven street settlement or to heavy traffic may be avoided. A curb cock and box installed outside the house limits and a water meter complete the installation.

Design of pipes

For detailed methods of design of gravity conduits and pipes, the reader is referred to standard texts on hydraulics. The design of pipes in a small water-supply system is usually confined to two main problems : (1) the computation of the size of pipe required to convey a specified amount of water under a given hydraulic gradient; and (2) the determination of the amount of water which will be delivered by a pipeline of a given size under a known pressure. These calculations, which are based on several assumptions, such as the water demand 20 years or more in the future, the roughness of the pipes at that time, etc., yield only approximate results. It is important, however, that basic topographical data from which static heads and pressures are determined should be as accurate as possible.

For the sake of convenience, tables giving the friction of water in small-size pipes, valves, and fittings are given in Annex 3, page 264. These tables may be used for the solution of the problems mentioned above.

Distribution systems

There are two main systems of distributing water in a community : the dead-end system and the gridiron system. As may be seen in Fig. 76, in the gridiron system the extremities of pipes are connected, with the result that dead-ends, and consequently stagnant water, are eliminated. In this layout the water circulates continuously throughout the distribution system. It is seldom possible to adopt this ideal system in small towns

and villages, which are often built along a stream, an irrigation canal, or a main road, and are elongated in general shape. However, it is desirable wherever possible to compromise between the two systems by laying

Fig. 76. SYSTEMS OF DISTRIBUTION
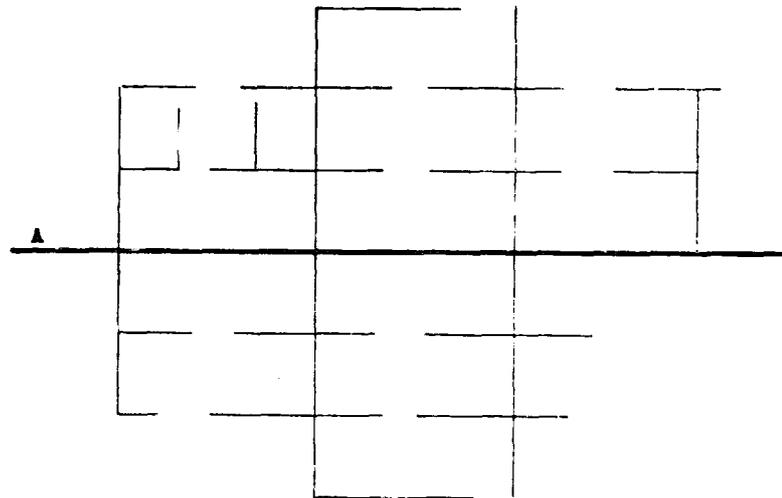
Dead-end distribution system
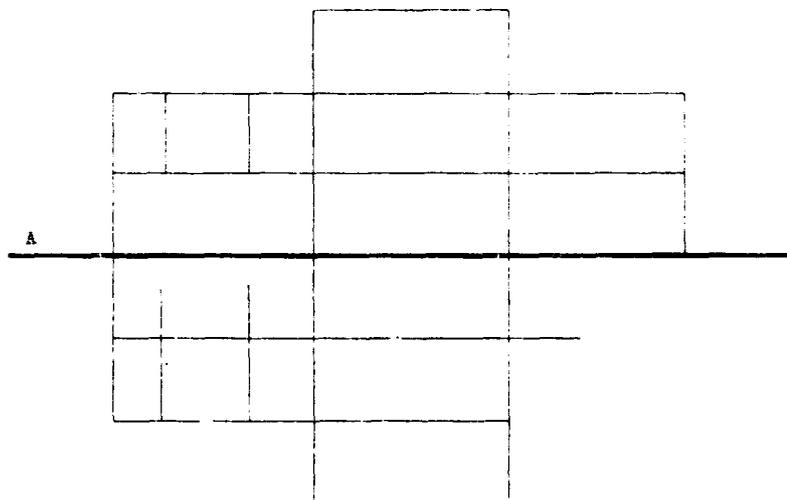
Gridiron distribution system

A = Main distribution pipe

out a gridiron pattern around the main residential or business districts and following the dead-end pattern for the rest of the system.

In designing the pipes of a dead-end distribution system, it is assumed that all the water needed in a particular district will be delivered at the end

of the pipe serving this particular district and at the minimum pressure selected. A similar assumption may be made for each pipe in a gridiron layout; in so doing the engineer is entirely on the safe side and his calculations result in pipes slightly larger than absolutely necessary. The more accurate methods of calculation (circle method, Hardy Cross method, etc.) are seldom used and are hardly justified for the design of small water-distribution systems. For such systems, the following design assumptions may be made (see also page 42):

(1) *Population*: depends on a careful study of the local situation and the available statistics. For economical design, the estimated population in 20-30 years' time should be selected. However, a minimum increase of 50% should be assumed.

(2) *Average daily consumption*: also depends on local conditions, such as the climate, the economic level of the population, the percentage of houses connected to the system in relation to those served by public fountains, the installation of meters, and the amount of waste. The percentage of houses with private connexions may vary from 20% to 100%. Recommended design figures are:

120 litres per person per day, for design of distribution systems;

15 litres per person per day, for public taps;

250 litres per person per day, for private connexions.

(3) *Maximum hourly consumption*: may be taken as four times the average daily consumption for populations of less than 1000 inhabitants, as three times the average rate for larger towns, and as double the average in a centre of 20 000 or over.

(4) *Pressure*: *minimum—10 m (15 p.s.i.)*: It may be desirable to set a maximum pressure for pipes in rural water-distribution systems, because they often do not receive the proper care at the time of installation, and also because of the time and difficulties sometimes involved in securing replacement fittings and in making repairs. In towns and villages where houses are not more than two storeys high, a maximum pressure of 50 m (70 p.s.i.) may be adopted.

When fire hydrants are used, the minimum pressure should be 25 m (35 p.s.i.).

(5) *Feeder pipe*: should be capable of delivering one-and-a-half times the average daily consumption of water at a velocity of flow not exceeding 2 m per second (6½ ft per second). The diameter should never be less than 5 cm (2 in.).

(6) *Velocity of flow*: should not be more than 1.8 m per second (6 ft per second) in main pipes, and about 0.90 m per second (3 ft per second) in distribution pipes.

(7) *Distribution pipes*: main distribution pipes should not be less than 5 cm (2 in.) in diameter. When fire protection must be provided, no hydrant will be served by a pipe smaller than 10 cm (4 in.) in diameter.

(8) *Service connexions*: not less than 12 mm (½ in.) in diameter. Each connexion should be made by means of a brass corporation cock tapped into the main followed by a short length (about 60 cm, or 2 ft) of lead (tin-lined) or copper tubing. This is continued by galvanized iron pipes 20 mm (¾ inch) or more in diameter and a control valve.

Laying of pipes

Everything which has been said under " Pipelines " (see page 168) applies also to the laying of pipes for the distribution system. The importance of identification of distribution pipes and fittings should, however, be mentioned and particularly stressed. It frequently happens that, after the construction of small water-supply systems, no maps and no records are kept regarding the location and sizes of pipes, valves, and other fittings. Under these circumstances it is not surprising to note that, with a turnover of staff, new personnel are ignorant of almost every detail of the water-distribution piping. As a result, the system deteriorates rapidly due to lack of proper maintenance, and so does the control of its operation and management. In addition, considerable time and money may be lost by digging up streets and destroying property in the search for pipes, valves, etc.

For these reasons, the importance of the establishment of permanent records cannot be overstressed. As the construction of the water system proceeds, final maps showing the exact location, sizes, and other relevant features of pipes, valves, and other appurtenances should be prepared. Usually these are shown on maps with respect to street kerbs; but, since in small towns and villages kerbs may be non-existent, other permanent points or objects of reference, such as houses, large trees, monuments, etc., should be selected. When pipelines are laid across open ground, it will be useful to mark their location by means of concrete beacons, built at frequent intervals, upon which the diameter of the pipe is shown.

Typical design of a small water-supply system

The following is an actual design of a water-supply and distribution system for a small town of 2500 estimated population. A topographical map of the town is given in Fig. 77 and the layout of the piping is shown in Fig. 78.

Design data

(1) Present population : 1340 inhabitants

(2) Estimated population in 20 years : 2500 inhabitants

(3) Percentage of persons to have private connexions : 70%

Fig. 77.   TOPOGRAPHICAL PLAN OF VILLAGE AND SURROUNDING AREA
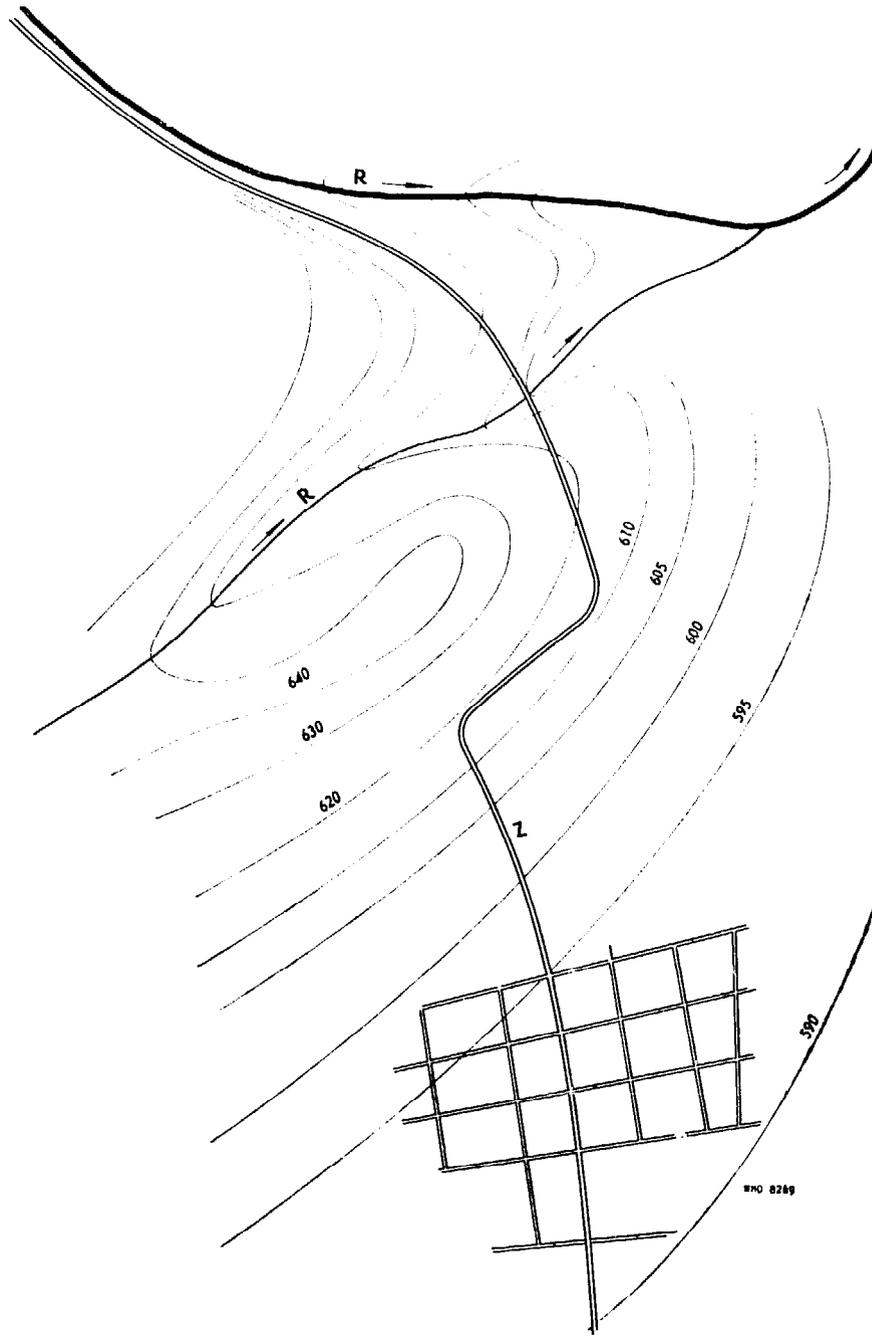
R = Rivers
Z = Main road through village
590 - 640 = Contour lines

Fig. 78. GENERAL PLAN OF DISTRIBUTION SYSTEM
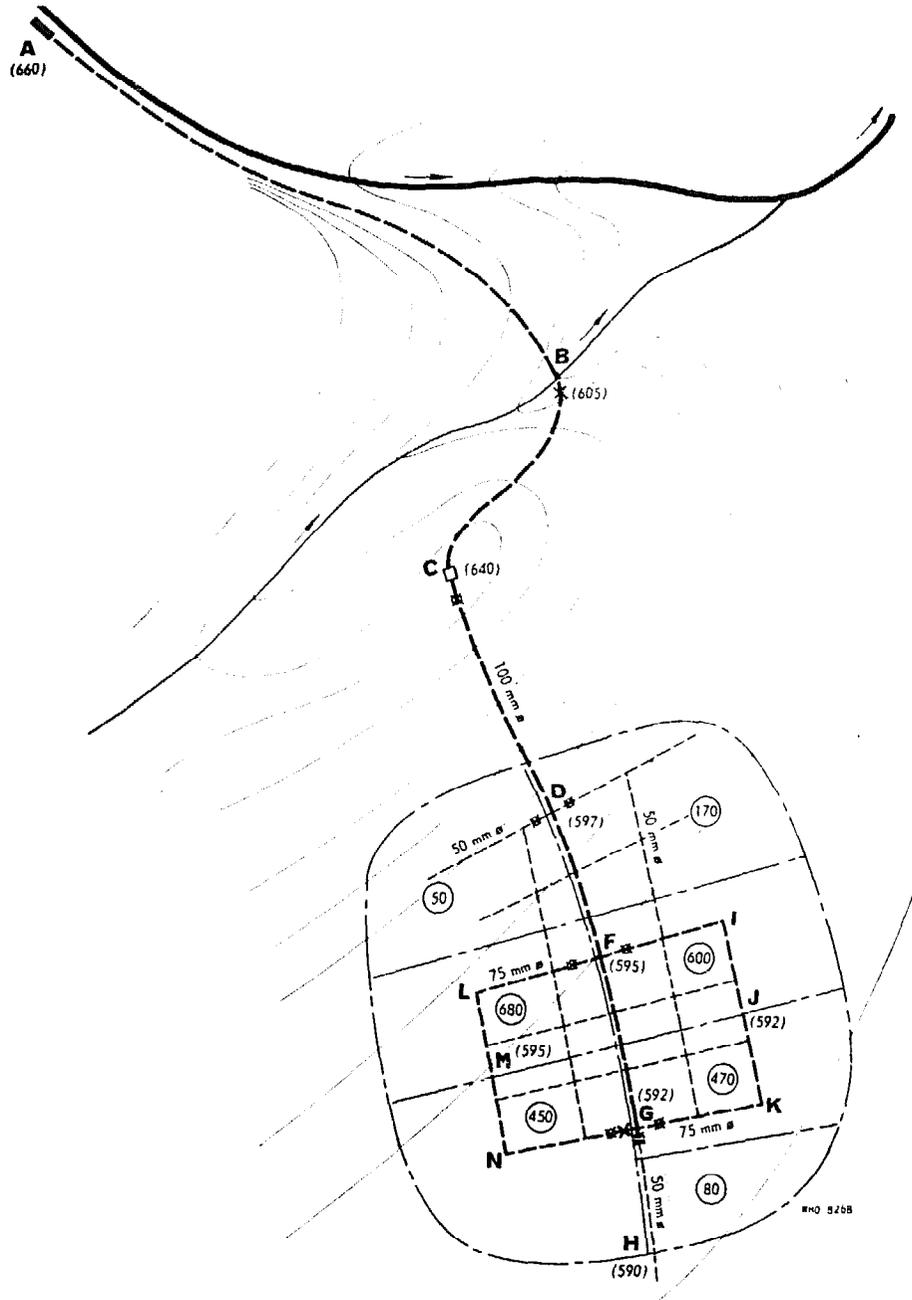
A = Infiltration gallery or river bank
B = River crossing by pipeline
C = Reservoir site
D-N = Distribution system
  ▨ Control valves
  × Blow-off valves at B and G
  ⑧⓪ Estimated population within lines
  marked thus : —— — —— —

(4) Percentage of persons served by public fountains : 30%

(5) Estimated number of persons served by private connexions : 1750

(6) Estimated number of persons served by public fountains : 750

(7) Average daily consumption per person served by service connexion: 150 litres (40 US gal.)

(8) Average daily consumption per person served by public fountains : 15 litres (4 US gal.)

(9) Estimated total daily consumption : 274 000 litres (72 400 US gal. approx.)

(10) Fire protection : " No provision "

(11) Density of population : as shown on map in Fig. 77

(12) Minimum pressure : 10 m (14.2 p.s.i.)

(13) Maximum pressure : 50 m (71 p.s.i.)

(14) Pressure required in system : 40 m (57 p.s.i.)

(15) Capacity of feeders : 150% of average daily consumption

(16) Pipes : cast-iron 18 years old and ordinary galvanized iron about 10 years old, coefficient C = 100 in Hazen-Williams formula

Supply pipe ABC

Capacity = 274 000 litres × 1.5 = 411 000 litres per day or 285 litres (75 US gal.) per minute

Available head = 660 m — 640 m = 20 m (65.6 ft)

Length ABC = 2350 m (7708 ft)

Available loss of head = 1000 × $\dfrac{20}{2350}$ = 8.5 m per 1000 m or 8.5 ft per 1000 ft

With a 4-in. (100-mm) diameter cast-iron pipe and a discharge of 285 litres (75 US gal.) per minute, the loss of head is 7.2 ft per 1000 ft or 7.2 m per 1000 m.

Effective loss of head = 2350 × $\dfrac{7.2}{1000}$ = 16.9 m (55 ft)

A 4-in. (100-mm) pipe will be used. It can transport up to 446 630 litres (118 000 US gal.) per day with the allowable loss of head of 8.5 m per 1000 m. According to the piezometric line from A to C, the piezometric level at B will be 642 m and the pressure at this point will be 37 m (53 p.s.i.).

Distributing reservoir

The capacity of the distributing reservoir will be equivalent to a one-day supply, i.e., 274 000 litres (72 400 US gal.). A concrete or masonry reservoir

of 12 m (39 ft 5 in.) square with a water depth of 2 m (6 ft. 6 in.) will cover the needs.   Its bottom will be at elevation 640 m.

Main CD

    Capacity = 285 litres (75 US gal.) per minute

    Pressure required at D = 40 m (57 p.s.i.)

    Piezometric elevation at D = 597 + 40 = 637 m

    Available head = 640 — 637 = 3 m (9.8 ft)

    Length CD = 300 m (984 ft)

    Available loss of head $= 1000 \times \dfrac{3}{300} = 10$ m per 1000 m or 10 ft per 1000 ft.

With a 4-in. (100-mm.) cast-iron pipe and a discharge of 75 US gal. per minute, the loss of head is 7.2 ft per 1000 ft (or 7.2 m per 1000 m).

    Effective loss of head $= 300 \times \dfrac{7.2}{1000} = 2.2$ m (7.2 ft)

    Actual piezometric elevation at D = 640 — 2.2 = 637.8 m

    Effective pressure at D = 637.8 — 597 = 40.8 m (58 p.s.i.)

Main pipe DF

    Population served between D and F = 50 + 170 = 220 inhabitants

    Population served by service connexions = 70% of 220 = 154

    Population served by public fountains = 66

    Average daily consumption between D and F = 154 × 150 litres + 66 × 15 = 24 090 litres (6360 US gal.)

    Average daily flow between D and F = 274 000 — 24 090 = 249 910 litres (66 030 US gal.)

    Capacity of main DF = 249 910 × 1.5 = 374 865 litres (99 040 US gal.) per day, or 260 litres (68.7 US gal.) per minute.

    Pressure required at F = 40 m (57 p.s.i.)

    Piezometric elevation at F = 595 + 40 = 635 m

    Available head = 637.8 — 635 = 2.8 m

    Length DF = 180 m

    Available loss of head $= 1000 \times \dfrac{2.8}{180} = 15.5$ m per 1000 m or 15.5 ft per 1000 ft

With a 4-in. (100-mm.) diameter cast-iron pipe and a discharge of 68.7 US gal. per minute, the loss of head is 6.1 ft per 1000 ft or 6.1 m per 1000 m.

$$\text{Effective loss of head } = 180 \times \frac{6.1}{1000} = 1.1 \text{ m}$$

Actual piezometric elevation at $F = 637.8 - 1.1 = 636.7$ m

Pressure at $F = 636.7 - 595 = 41.7$ m (59.2 p.s.i.)

Main FG

It will be assumed that both sectors FIKG and FLNG can be supplied from either F or G and that, therefore, the output at G is equal to the input at F, i.e., 260 litres (68.7 US gal.) per minute.

Pressure required at $G = 40$ m (57 p.s.i.)

Piezometric elevation at $G = 592 + 40 = 632$ m

Available head $= 636.7 - 632 = 4.7$ m

Length FG $= 200$ m

$$\text{Available loss of head } = 1000 \times \frac{4.7}{200} = 23.5 \text{ m per 1000 m}$$
or 23.5 ft per 1000 ft

A 3-in. (75-mm) diameter cast-iron pipe is just too small. A 4-in. (100-mm) pipe and a discharge of 68.7 US gal. per minute correspond to a loss of head of 6.1 ft per 1000 ft. or 6.1 m per 1000 m.

$$\text{Effective loss of head } = 200 \times \frac{6.1}{1000} = 1.2 \text{ m}$$

Actual piezometric level at $G = 636.7 - 1.2 = 635.5$ m

Pressure at $G = 635.5 - 592 = 43.5$ m (61.8 p.s.i.)

Pipe FIKG

The population supplied in the two main sectors FI and GK being relatively small, it may be assumed that the whole population of 1070 inhabitants (i.e., 600 + 470) is served by pipe FIKG at G. In fact, this would be the case in the event of a break on the main FG.

Population to be served $= 1070$

Population to be served by service connexions $= 70\%$ of $1070 = 749$

Population to be served by public fountains $= 30\%$ of $1070 = 321$

Average daily consumption $= (749 \times 150) + (321 \times 15) = 117\ 165$ litres (30 960 US gal.) per day or 81 litres (21.5 US gal.) per minute

Pressure required at end of pipe at $G = 40$ m (57 p.s.i.)

Piezometric elevation at G = 635.5 m. (Actually this figure should be slightly higher since the amount of water flowing through main FG is less than 68.7 US gal. per minute assumed above).

Available head = 636.7 — 635.5 = 1.2 m

Length FIKG = 400 m

Available loss of head = $1000 \times \dfrac{1.2}{400} = 3$ m per 1000 m or H 3 ft per 1000 ft

A 3-in. (75-mm) diameter pipe and a flow of 21.5 US gal. per minute correspond to a loss of head of only 2.9 ft per 1000 ft or 2.9 m per 1000 m and, consequently, will be adopted. The same diameter of pipe will be applied to main FLNG which serves an almost equal population under the same topographical conditions.

Pipe GH

The population served by this pipe-line is very small, only 80 inhabitants, and may obviously be served by a 2-in. (50-mm) diameter pipe.

Pumping system

If, instead of using a gravity system, it were decided to develop a satisfactory source of supply at or near the river crossing at B, it would be necessary to pump water up to the reservoir at C for storage purposes. This source might be a well, an infiltration gallery or, even, a small water-treatment plant, depending upon the circumstances. Assuming the level of water at the source to be 600 m and at the top of the reservoir to be 645 m, the following data would obtain :

Static lift = 645 — 600 = 45 m (147.6 ft)

Length of booster pipe BC = 480 m (1574 ft).

Discharge of pump (Q) = 274 000 litres (72 400 US gal.) in 8 hours, or 9.51 litres per second (0.336 cubic foot per second or 151 US gal. per minute)

Diameter of booster pipe (assumed) = 150 mm (6 in.) cast-iron, friction coefficient $C = 100$.

Loss of head in pipe at rate of discharge = 3.62 ft per 1000 ft, or

3.62 m per 1000 m, which corresponds to : $\dfrac{3.62}{1000} \times 480$ m = 1.74 m for pipe BC.

Total lift $(H) = 45 + 1.74 = 46.74$ m (153.3 ft)

Pump efficiency (assumed) $= e = 60\%$

Brake-horsepower required $= \dfrac{Q \times H}{3960\,e} = \dfrac{151 \times 153.3}{3960 \times 0.6} = 9.7$, say 10 b.h.p or 10.14 CV.

Assuming cost of pumping at 20 cents (US) per 1000 US gal. delivered to the reservoir, the operating cost would be :

$$\frac{72\,400}{1000} \times 0.20 = \text{US \$14.48 per day of pumping.}$$

The pumping station should also include a standby pumping unit of similar capacity but driven by a different type of power, i.e., a diesel engine if electricity is used for the other pump motor.

Public fountains

Public fountains are inevitably a part of all water-distribution systems in small, rural towns. There are several problems involved in the design and locating of these apparently simple structures. Such questions as the number, distribution, and adequate siting of fountains, the type of faucet or outlet to be used, the height of the loading platform, the nuisance created by inadequate drainage around the fountains, and the charge for water—all must be determined beforehand. The answers to most of these questions depend almost entirely on local circumstances, but the experience already acquired in several countries may be helpful to the water-supply engineer responsible for design, and to local authorities.

Public taps should be installed in the poorer sections of the village where the possibilities of house connexions are least. Experience shows, however, that public fountains tend to discourage the installation of service connexions, and cannot be relied upon to any significant degree to solve the public health and personal hygiene problems of the population. While it may be necessary to provide public fountains, their number should be kept to a minimum, special care being given to their proper location in the town districts to be served (see " Objectives and concepts ", page 18).

Attention should be paid to local customs of carrying burdens and, consequently, to the height of a fountain's loading platform. Water may be carried in a variety of containers, such as pottery or brass vessels, 20-litre (5-US gal.) tins, buckets, and assorted cooking utensils. It may be transported on the head, shoulder, or back, or in the hand, or with the help of a yoke. Ideally the platform on which the container is filled should be only a little lower than the height at which the load is carried, to eliminate unnecessary lifting. It should provide room for more than one container. The spout should project far enough to reach the mouth of the container, thus avoiding the need to tip a jug towards the pillar. Possibly dual platforms are needed, one at a little lower than the knee, the other at about shoulder height. Where jugs with round bottoms are used, there might be a depression to give firmer support.

As far as is known, a public tap which will withstand prolonged use and abuse has not yet been developed. Public fountains are repeatedly broken

Fig. 79.　POSSIBLE ARRANGEMENT OF PUBLIC FOUNTAIN

Section A - A

Section B - B

WHO 9217
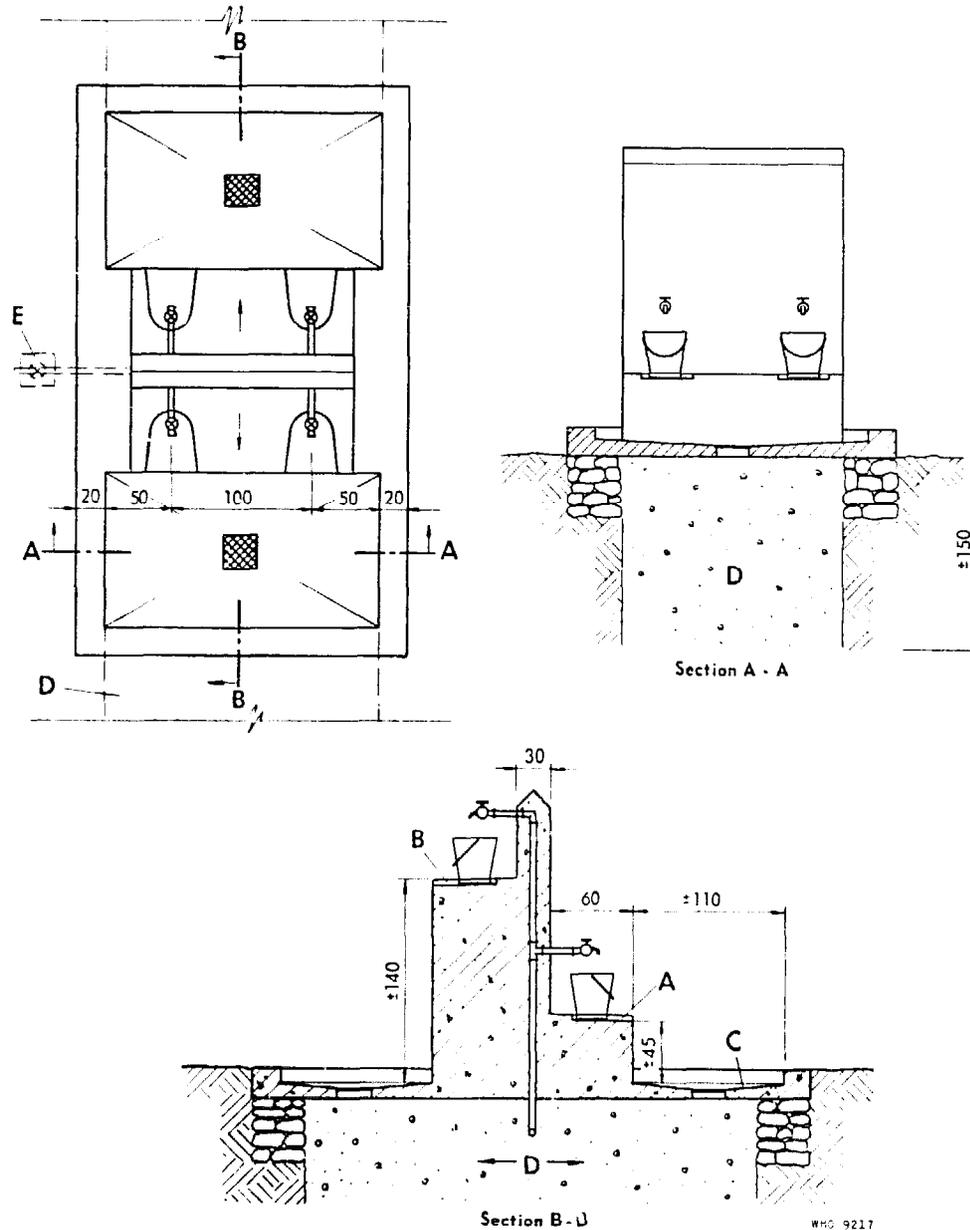
Measures are in centimetres.

A = Platform level at about knee height
B = Platform level at about shoulder height
C = Hard-surface floor
D = Soakage pit : length may extend
　　　beyond limits of fountain
E = Control valve

　　Public fountains should be constructed of the most durable materials possible because no part of the water system will be required to take so much abuse.　It is usually possible to construct the platform and faucet support so that only the most excessive abuse will damage it.　The weakest part is the faucet itself.　This should be the strongest available.

through rough usage and are frequently responsible for considerable water losses, when pressure is high and the discharge orifice is large. Pressure-reducing valves and a reduction of tap sizes will help to limit losses. Public fountains require constant supervision and frequent repairs. One good solution for the operation of fountains is the adoption of a system by which a small charge is made for each can or bucket of water delivered at the fountain, this money being used to pay the wages of a public-water-tap operator. Various methods of management of public taps are discussed elsewhere (see page 241). It is necessary to remember that either poor location of fountains or a high water charge, or both, can defeat the public health objectives of the water-supply system by discouraging its use by the population in favour of a return to the old, unsafe water sources.

Every public fountain should be built with some kind of waste-water-disposal system. Water standing around public fountains can create a serious nuisance and discourage their use. Fig. 79 shows a typical fountain and drainage scheme.

Water losses

There are leaks in every distribution system, no matter how well it is built. But there must be a limit to the amount of water which may be lost in this way; and, in small water-distribution systems especially, there is a need for control of leakage and waste.

The control of water losses usually involves some kind of an inspection system, either personal or mechanical. The mechanical system of inspection implies the use of water meters and gauges which in turn require maintenance and attention and, therefore, are beyond the resources and possibilities of many small towns. Since the major losses in most small towns are to be found in the houses and public fountains, it is here that most effort must be concentrated. A system of private house inspection should be developed which will lead to the discovery and repair of leaky faucets and valves and to the elimination of waste in general. The amount of water lost through carelessness of customers sometimes reaches staggering proportions; it is not uncommon to find towns wasting as much as 75 % of the water supplied.

Laundries and Baths

Public laundries and baths are often included as a part of small town water-supply systems. These are especially needed in areas where bilharziasis (schistosomiasis) is prevalent. In such areas the transmission of the disease takes place mostly through contact of the skin with river, pool, or canal water which is infected with the parasite of the disease. The danger is particularly great for children who, in the warm climates of bilharziasis-infested countries, spend much of their play-time wading in rivers.

water pools, or irrigation canals which are easily infected by the faecal and urinary discharges of apparently healthy disease-carriers. The provision of public laundries, public baths, and swimming-pools constitutes one of the steps towards preventing the transmission of this debilitating disease.

Public laundries and baths are generally well received by the public and used as long as they are properly maintained. If, however, reasonable cleanliness and maintenance cannot be assured, it is better to spend the construction funds on something else.

In the design of a public laundry, the following points should be carefully observed :

(1) The planning of an installation which is practical and conforms reasonably well to local customs. For this purpose, the designer should make a close preliminary study of local laundering processes.

(2) The provision of ample drying space. Overhead lines or concrete slabs can be constructed, depending on local customs. In some areas, women refuse to hang clothes on lines and insist on laying them flat on the ground.

(3) The provision of a sufficient supply of water. Although this sounds an obvious requirement, it is not uncommon to find public laundries in which the pipes are too small to supply enough water for laundering processes. The construction of a small storage-tank at the side will help during hours of heavy use of the fountain.

(4) The chemical examination of the water supply for its possible contents of iron and manganese compounds. These substances are capable of staining clothes a reddish-brown or black colour.

(5) The drainage of waste water in the vicinity of the public laundry installation.

Similarly, in the case of public baths, the designer should pay particular attention to the physical quality of the water furnished (turbidity, colour, odour), to the drainage of waste water, to the separation of sexes, etc. In the case of swimming-pools in bilharziasis-infected areas, it may even be necessary (depending upon the source of water supply) to enforce chlorination of the water to destroy bilharziasis worms (cercariae) in the water. In filtered water cercariae will be killed in 10 minutes by application of chloramine with a 1 p.p.m. chlorine residual at 1 minute. In unfiltered water, they will be killed within 10 minutes by chloramine with 1 p.p.m. chlorine residual at 30 minutes. With calcium hypochlorite solution, cercariae will be destroyed within 20 minutes with a chlorine residual at 30 minutes of 0.75 p.p.m.

Protective Measures

The protective measures needed for water-distribution systems aim at conserving the quality of the water obtained at the source all the way to consumers' taps. At many points in a system the quality of the water

may be altered by any of several factors, among which the following may be cited : the ingress of exterior polluted water through faulty joints or leaks; the growth of bacteria and micro-organisms in the distribution system itself; the solution of chemical substances from the metal system itself; the solution of chemical substances from the metal pipes or from the cement mixtures or other building materials employed for the construction of reservoirs or cisterns; and, finally, the gross pollution obtained from accidental cross-connexions with polluted water pipes.   It should be noted that protective measures need to be considered right from the inception of a water-supply and distribution project and should be designed as part of the system.   They should also be given attention during construction and pipe-laying operations.   It is a fallacy to believe that the disinfection carried out after construction and before operation of the system will be sufficient to sterilize completely the surfaces with which the distributed water will come into contact.

The principal sanitary measures involve the following :

(1)   The proper location of reservoirs and distribution pipes.   These should be kept away from direct contact with, or proximity to, all sources of pollution such as sewage or storm-water ditches, latrines, etc.   Distribution pipes should not be submerged in surface water pools and, wherever possible, should be placed above sewers or drain pipes.

(2)   Watertightness of reservoirs and pipes and the elimination of leaks.

(3)   The maintenance during 24 hours a day of ample pressure in the system.

(4)   The planning of the distribution system in such a way as to permit effective circulation of water and a reduction in the number of dead ends, which favour the growth of bacteria and micro-organisms and the deposition of sediment.

(5)   The elimination of cross-connexions.

(6)   The prevention of back-flow and of entrance of outside water or materials through such openings as the overflow pipes and manholes of reservoirs, etc.

(7)   The use of pipe and construction materials which will not lend themselves to corrosion and solution into the water, thereby creating toxic hazards to the consumers.

These sanitary measures are usually specified in great detail by governments' sanitary codes or regulations, which should always be consulted by the designing engineer.

Hydropneumatic or Pressure System for Individual Homes

When water is unobtainable by gravity and is needed under pressure for use in individual homes, barns and farm installations, and small-scale irrigation, the hydropneumatic—also called " pressure "—system may be

installed with advantage. Usually such a system is employed where electric power is available for its operation.

As shown in Fig. 80, this system consists essentially of an electrically driven pump and a pressure tank partly filled with air. Water is pumped into the lower part of the tank, compressing the air above it. When the pressure reaches a predetermined maximum figure (usually 2.72 atm., or 40 p.s.i.), the automatic switch opens and shuts off the motor and pump. As water is drawn out of the tank, the pressure drops; and, when it reaches a pre-set minimum (usually 1.36 atm., or 20 p.s.i.), the automatic switch closes and starts both motor and pump again.

Fig. 80.   PRESSURE TANK SYSTEM
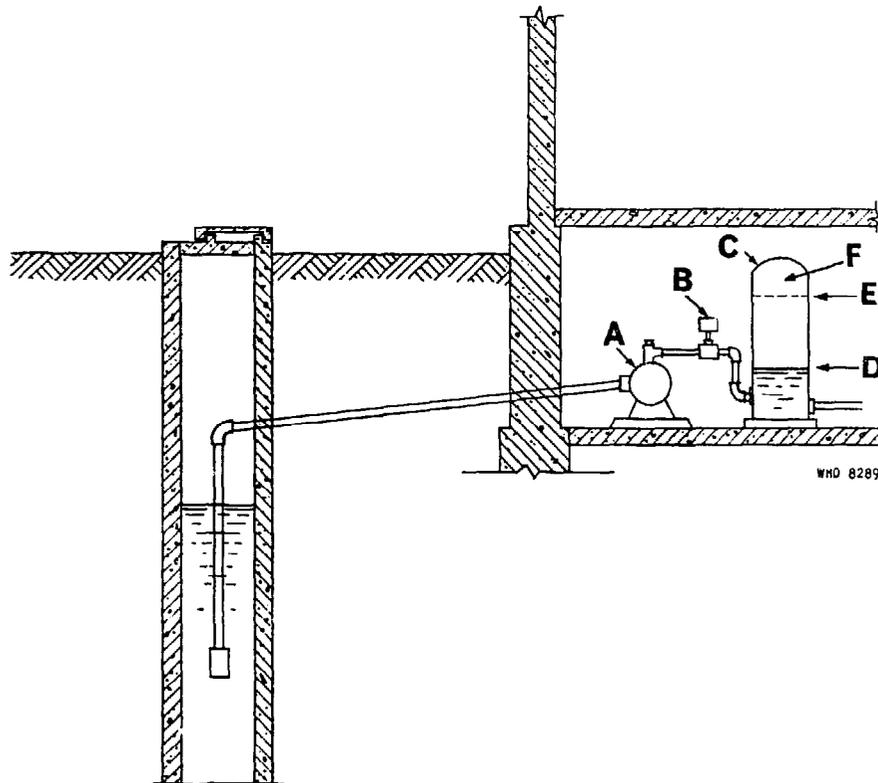
A = Pump and motor
B = Automatic switch
C = Pressure tank
D = Water level corresponding to minimum pressure (usually 1.36 atm., or 20 p.s.i.)
E = Water level corresponding to maximum pressure (usually 2.72 atm., or 40 p.s.i.)
F = Air in tank

Various types and designs are available on the market and are usually sold together with instructions for their installation, operation, and maintenance. The pump used may be of either the displacement or the velocity

type. When a reciprocating pump is used, the system should always be provided with a pressure-relief valve, since dangerous pressures may be built up in the tank if, for unexpected reasons, the automatic switch should fail to operate. For ordinary household needs, a pressure tank of about 160-litre (42-US gal.) capacity will suffice. If peak demands should be created by such circumstances as lawn-sprinkling or irrigation, a larger installation will be recommended by manufacturers or their commercial representatives. Electrically driven pressure systems are compact; and, being completely automatic, they require a minimum of attention and maintenance. An ordinary household unit equipped with a 160-litre (42-US gal.) tank and capable of a maximum pressure of 4-4.8 atm. (60-70 p.s.i.) may be obtained on the market at an average cost of US $160.00 (1958).

MANAGEMENT OF WATER-SUPPLY SYSTEMS

Chapter 8

IMPORTANCE OF MANAGEMENT

It has been rightly said that the degree to which a water-supply system fulfils its public health function varies almost directly with the efficiency a..d effectiveness of its management. This statement is corroborated by experience everywhere. In the planning of small water-systems, it sometimes happens that enthusiastic officials and designers give too little consideration to the management phase of water-supply schemes and to the development of appropriate administrative devices for their smooth operation. Too often, public opinion regards the management function of waterworks officers as a routine job which consists of handling daily occurrences and which grows and expands under its own momentum. This assumption is far from the true facts, as good management of a water system, whether large or small, embraces a number of functions, such as :

(1) provision and maintenance of adequate facilities;
(2) good and smooth operation;
(3) provision of a satisfying service to consumers;
(4) efficient maintenance;
(5) establishment of sound fiscal methods;
(6) development of equitable water rates;
(7) efficient organizational structure and procedures;
(8) development of technical and financial plans for future expansion;
(9) supervision of personnel; and
(10) control of equipment and supplies.

Broadly speaking, the management phase of water supply can be divided into two parts : the first part, administration, deals with organization, records, finances, personnel, and supplies; the second part, operation and maintenance, is concerned with the conveyance and delivery of safe water from source to consumers. Both are important and interdependent and must be co-ordinated to effect a unified and well-integrated procedure. Another significant aspect of management is timing. Good management anticipates rather than follows needs, and maintains alertness in reviewing and revising operations and procedures as appropriate.

The paramount importance of the public health aspects of rural water-supplies has been stressed in the opening chapter of this monograph. The economies and managements of these systems are normally next in line, and deserve full consideration from the persons or agencies promoting their construction. Under poor management, equipment and facilities, as

well as water quality, are allowed to deteriorate; records are non-existent; and revenues—if any—are used for other municipal or political purposes. As a result, the health and welfare of the consumers are seriously jeopardized, service is curtailed, and the costs of maintenance and replacement soon become prohibitive for the community.

Responsibility for Management

The responsibility for the managements of small-town water systems may fall on either the local municipal government, the state or provincial government, the federal or central government, or a private company. It is rather rare to find private companies in charge of the administration and operation of rural community water-supplies. Even in the USA, the great majority of rural and small-town systems are publicly owned and operated under the supervision of the town's mayor, a city manager, or a public utility commission. Of the three forms of top management, the public utility commission is probably the most desirable since it is normally non-political in character and is responsible only to the public which it serves. It consists of between three and five members of the community, whose terms of service overlap in order to provide for continuity of policy and action. In most other countries, rural water-supplies are usually administered by the local government (mayor) and, sometimes, by the state or the central government. In several countries, especially in Western Europe, water supply (or sanitary) districts which include several towns and adjoining rural areas are organised and operated jointly by the local governments concerned.

It is important, in the promotion phase of rural water-supply development, to decide early which government agency shall be responsible for management after construction is completed. Experience so far indicates that the local people, through their own municipal administration, should bear the primary responsibility, with assistance provided as necessary from a higher level of government. This should be a basic policy for the following reasons :

(1) When help is given or imposed from above on a continuing basis, the local population or municipality does not share or participate in the undertaking and does not develop a sense of ownership and pride in the system. This type of help does the least to encourage local communities to take action in solving their own problems.

(2) Eventually the local people must assume the major responsibility for utilities of this kind, which are purely local in character and which they alone use.

(3) Competence in management can be gained only through responsible experience in it.

(4)   The immediate effect of good or bad management can be felt by the local population, which can bring pressure to bear for changes or improvements when these are needed.

(5)   Administrative interest and efficiency tend to be directly proportional to the proximity of those persons responsible.

Traditionally, health administrations, in their duty to safeguard the public health, have been concerned with the operation of water systems only from the standpoint of water-quality control.   This is generally true in the more technologically developed countries of Europe and America.   In less-favoured countries, where management experience and ability are usually lacking among the rural folk, the health administrations, in stimulating the development of rural water-supply systems, may need to give equal consideration to all facets of these developments—promotion, design, financing, construction, and management as well.   Experience in these countries shows that in most instances small communities are totally unprepared and unable to manage a new water-supply system.   Through its public health engineering department, the health administration can be of considerable assistance to such communities in giving locally recruited persons the training and managerial experience which they require to keep the system in good operating condition and, what is most important, to ensure that the water delivered to consumers is safe and in adequate quantity for personal hygiene and household needs.   It is quite logical that, eventually, the actual administrative assistance should be taken over by the municipality itself or some other government agency.   However, in this case, which may be an intermediate developmental step, the health administration must keep a prime interest in the operation of the system, beyond the simple function of checking the quality of the water delivered to consumers. Finally, the time will come when local technology, facilities, and experience have sufficiently developed to enable the health administrations to resume their traditional role.   At that time the water system will be operating smoothly and there will be local pressure for its continuance.   It is important, therefore, that comprehensive assistance be given from the beginning, and not after trouble arises.   Proper aid in management is likely to be one of the best preventive measures.

Such a programme is in operation in Brazil at the present time and is yielding excellent results.   It is the SAAE (Serviço Autônomo de Aguas e Esgotos, or Autonomous Water and Sewer Service) programme, according to which the Brazilian Public Health Service provides assistance to communities by area.   A municipality signs a formal agreement with the Health Service and agrees to set up an autonomous water department to which it delegates definite authority and responsibilities.   The agreement is made for one year, during which time the new water department, employing local staff and receiving both technical and administrative assistance from the engineering section of the Health Service has freedom to operate within

its terms of reference. If it does a good job during the year there is usually no problem in obtaining an extension of the agreement; otherwise, the year's work is critically reviewed with the aim of improving operations and eliminating administrative bottlenecks.

One important result of this arrangement is that the water-supply system can be efficiently operated away from political and similar influences. No longer is it necessary to cultivate and to favour special groups within the communities. Local authorities are usually pleased with this arrangement, which relieves them of considerable difficulties in turning down favour-seekers who want free water, pipe extensions, bills cancelled, etc. In most rural, undeveloped areas of the world, these are very real problems, which can often be embarrassing and, at the same time, detrimental to the maintenance of efficient administration and of good public relations.

For each area covering from 10 to 15 small towns, the Health Service maintains a team composed of a well-trained mechanic, an administrative officer, and an engineer. These specialists visit each town routinely to work with the local SAAE staff. They are also on call for emergencies, especially the mechanic. Strangely enough, however, the experience has been that, once the system has begun to function, maintenance by local staff has improved quickly to a point where emergencies are few and far between.

Early Steps towards Effective Management

Although the management phase of a water-supply system is the last item in the list of steps required for its development, it is most important that it be kept in mind by policy-makers and engineering designers during the earliest planning stages. The engineer who makes the preliminary field investigations and designs can, by his decisions, facilitate or complicate future operation and maintenance problems. This will depend on whether he is searching simply for a solution, or for the best possible solution. Often, as a result of haste, these studies become less thorough than they should be once a solution for the town's supply has been found. It has been said before that the engineer in charge of field investigations and design controls one of the most important phases, which bears heavily on the future operation of the project. If by diligent work he can eliminate a pump, an engine, another piece of equipment, or a treatment process, he is thereby removing another possible obstacle to efficient operation. The water-supply policy, of which mention has been made previously, is expected to deal, among other things, with this aspect of design. An understanding of the operational problems of small water-systems, perseverance in the search for simple solutions, and vigilance in approval of projects are the best possible measures to facilitate management of these systems and, thus, to ensure the fulfilment of their function.

From the administrative standpoint, proper management of a water-supply system, no matter how small, requires operating funds, personnel. and organizational services. Since these things are within the province and control of local authorities, early negotiations should be undertaken, and a considerable area of agreement should be reached before the project gets into the construction stage. These negotiations are not always easy, as some town officials, whether elected or appointed, will jealously guard their right to manage their own affairs and their own funds as they wish, even though they may have had no previous experience in water-supply management. The main points to be covered by the agreement include:

(1) the necessity for the town to retain personnel trained in water-works operation, and to replace them—when the need arises—only with other trained individuals;

(2) the scope of managerial and technical assistance to be provided from outside sources;

(3) the establishment of schedules for water rates.

It is obvious that in most instances a certain amount of compromise will be needed on the part of the local government in exchange for better assurance of proper waterworks operation.

Chapter 9

PERSONNEL AND TRAINING

Type of Personnel

The number of personnel employed to manage and run small water-supply systems depends upon the size of the distribution system (especially the number of customers) and the extent of water treatment, if any. It should not be expected that high-calibre personnel will be found in small towns and villages for the positions available. However, it will often be possible to recruit and train potentially good employees for both administrative and operational functions. One of the methods which has proved successful in many places consists of using the construction period to select and train the key personnel who, later, will be responsible for operational duties. During this phase, the men have an opportunity to learn how the system has been put together and works; and, in this way, they can best understand and perform the maintenance work which is expected of them. At the same time, the men selected for future management duties can be given a chance to work in all administrative and technical aspects of the water-supply project, which will contribute to their future effectiveness. The actual selection of these men may, in some instances, be a delicate matter, inasmuch as their employment may be the normal function of the local government. With tact and understanding, however, it should be possible to find candidates who are acceptable to the local authorities and who possess the minimum qualifications required for the positions. In a typical small water-supply system, the personnel might consist of the men necessary to operate the water-treatment units (if any), and of one or two men in charge of all distribution-system operation and maintenance. The office work might be handled by two or three well-trained clerks who might make meter readings, issue customers' bills, receive payments, and do the necessary accounting work. This administrative staff might be supervised, and assisted as required, by local government officials (see : " Responsibility for management ", page 228).

Salaries usually constitute the next barrier to the recruitment of the best men available. In small-town water systems, salaries are seldom attractive, as a result of which a turnover of personnel should be anticipated. Experience has repeatedly shown, however, that the increased salary paid for better-qualified waterworks personnel is more than offset by their greater adaptability and effectiveness.

As indicated previously (see page 173), it is necessary to keep the local level of management and operation as high as possible if a community water-system is to perform its public health function. In discussing the need for such programmes, the American Water Works Association has stated : " It is extremely important to remember that small water systems do not imply either small problems or small responsibilities ". [2] The International Water Supply Association [23] has said (page 637): " Contrary to general belief, and one might also say practice, it is the medium-sized and small under-takings which would benefit most from employee training. In large organizations, work is divided and sub-divided into sections, each one being controlled by a person of technical, administrative or organizing ability, who is, or becomes, a specialist in his particular sphere. In small undertakings, each person in a supervisory position has to control a greater number of functions, and without the benefits of training he is bound to be less efficient in any individual function than his counterpart in a large organization. " For this reason health administrations should support, and if necessary should organize, training programmes for waterworks operators.

Training

Short courses of from one to four weeks' duration on various aspects of operation and management have been held in many countries with considerable success. In recent years, the World Health Organization has sponsored such courses in several continents for the benefit of a large number of its Member States. In-service training programmes and correspondence courses have also been organized in some countries.

The objectives of a well-rounded short course are : [2]

(1) to improve the group level of occupational efficiency;

(2) to acquaint the group with new developments;

(3) to develop among the members of the group a concept of their individual responsibility to the community;

(4) to develop among the members of the group a better understanding of human relations;

(5) to bring about an increased community appreciation of waterworks operation.

In many instances, however, it will be necessary to restrict the number of subjects taught at such courses because of time limitation, the educational level of the participants, and other factors. This is especially true of short courses for the operators of small water-systems, who should preferably be shown how to perform a number of specific jobs well, and for whom the courses' contents should be suitably designed. Later, as more courses are organized and the training programme advances, it will be to possible bring the same persons back for further and more-advanced instruction. Teaching should stress the practical aspects of the subjects covered and should

include a minimum of formal, didactic lectures. The training should preferably take place at a well-equipped and well-run water plant.

The following subjects or groups of subjects may be included in the curriculum of such courses : [2]

Mathematics

    Arithmetic, algebra, and geometry
    Units of measurement
    Practical applications

Chemistry

    Valence, atoms and atomic weights
    Equations
    Standard solutions
    Chemical reactions
    Laboratory control tests
    Qualitative, quantitative, and organic
      chemistry

Bacteriology

    Disinfection and sterilization
    Media
    Laboratory techniques
    Coliform tests
    Interpretations
    Standard methods
    Epidemics

Water treatment

    Turbidity
    Sedimentation
    Taste and odour
    Colour
    Algae and algicides
    Aeration
    Disinfection
    Filtration
    Corrosion
    Iron removal
    Other courses as required (coagulation,
      chemical handling and feeding,
      softening, dechlorination, fluori-
      dation, ozonization, safety
      of personnel)

Other courses
    Public health regulations

Engineering and maintenance

    Hydrology
    Wells, springs, infiltration galleries
    Hydraulics
    Maps and records
    Maintenance and repair — meters,
      mains, hydrants, valves, feeding
      equipment
    Packing materials
    Water storage
    Disinfection of mains
    Pumping machinery
    Emergency operation
    Pipe joints (types)
    Trenching, shoring, etc.
    Freezing, thawing
    Plant layout and design (minor)

Administration

    Accounting
    Rates
    Meter reading
    Billing
    Collecting
    Office management
    Depreciation
    Labour relations
    Public relations
    Safety practices

Farm and watershed sanitation

    Cross connexions
    Electricity
    Lubrication
    Stream measurement
    Financing
    Economics of water softening
    Radioactivity
    Microscopy
    Specifications of pipes and equipment
    Fire protection
    Leak detection
    Stream pollution
    Plumbing

The programme of training may be accompanied, when circumstances permit, by a programme of examination and certification of water-system

managers and operators, several grades being established for each category of personnel according to the level of training received. Such a programme, which may be undertaken in collaboration with local education authorities, will help to create an incentive on the part of the water-supply staff for technical development and progress towards more-responsible positions. It will also help to reduce turnover of personnel.

Development of the Service Concept

On the question of management of water systems for rural areas and small communities, one cannot insist too much on the need to develop in the mind of every waterworks official, whether office or field employee, the concept of " service to the community ". Both the administration and the operation of a water system, large or small, should be geared towards the provision of a satisfactory service to the consumer. In many rural areas, this will be a novel idea. Often rural or small-town folk do not think of public utilities as agencies from which they can expect or demand service; then the utilities, and the water supply as well, are thought of in terms of the mail service which is poor and intermittent, the train which is usually late, and lights which barely glimmer. Much effort should be made by the responsible agency, when planning the management of the water-supply system, to ensure that neither the public nor the waterworks employees develop this sort of attitude. The objective should be to make the employees understand the importance of giving a satisfactory service to consumers and their role and responsibility in so doing. On the other hand, the local population needs to develop a sense of ownership and pride in the water system and to understand that it has a right to demand better service. These processes are neither simple nor quick. Much will depend on the effectiveness of management and of its success in establishing good public relations. Once these are obtained, the service concept will grow and become generally understood and accepted. The critical time is in the early stages.

Chapter 10

ADMINISTRATION AND FINANCE

Administration

The organization necessary for the administration of a small water system depends chiefly on the size and complexity of the system and upon the method of collecting water fees. In some towns, the administration of the water system is merged with that of other public utilities, such as the electric service, for which the consumer also pays. This is not to be recommended, however, as in virtually every instance water funds are diverted to pay for whatever is politically important at the time. The same applies to the operation personnel, the sharing of whom results in a rapid deterioration of water facilities. Wherever possible, the water department should have its own field personnel in such numbers that the men are kept fully busy, with no time left over for other municipal functions. In this way the required work of maintenance and operation will be done and responsibility will be easily placed. Some of the routine office jobs, however, may be handled jointly with similar work done for other utilities, so long as the necessary work gets done.

The administrative work may be divided into the following functions : (1) accounting of funds; (2) budget estimating; (3) water-rates calculations; (4) billing; (5) collection of water fees; (6) paying; (7) record-keeping (personnel, equipment, supplies, inventories); (8) purchasing; and (9) customer relations.

It may be noted that the basis of good water-system administration is the keeping of suitable records and accounts. Recently, Haley [20] studied the matter in an excellent paper, on which the following paragraphs are based. Records, he said, can generally be classified as financial and statistical. Statistical records are those dealing with operational details, such as water pumped or delivered by gravity and sold, new services connected, and pipes laid. Financial records deal with the handling of money and investment. Sometimes water department officials keep a good deal of statistical information in their heads, with the result that much good data are lost when they leave the department.

Records are necessary, but keeping too many of them can also constitute a serious drawback. Furthermore, records should be simple.

The same is true of an accounting system, which must be able to give accurate, up-to-the minute information that includes the many factors which do not re-occur every month, such as depreciation, insurance, taxes, and inventories. A cheque-book can sometimes serve as the only accounting record of a small business; but much valuable data will, however, fail to be recorded.

The statistical information required includes :

(1) the amount of water pumped into the system or delivered into the system by gravity;

(2) the amount of water sold to the customers;

(3) consumer habits and characteristics;

(4) rate of increase in number of customers;

(5) system losses;

(6) system maps;

(7) delivery capabilities of the system at various points;

(8) relation of supply to demand.

The last three items pertain to operational records.

All these records can be tabulated and charted to give an accurate estimate of future trends. In small water-supplies, system losses are particularly important. Haley[20] estimates that a system consistently losing 25%-30% of its water will have about 9%-10% revenue loss.

The following are financial records that are necessary :

(1) proper valuation of the system;

(2) depreciation of the system;

(3) operating expenses;

(4) reinvestments in new capital improvements;

(5) cash position;

(6) long-term debt.

These items can be further subdivided, if required by local administrative regulations. The *Manual of water works accounting* of the American Water Works Association, or similar guides sometimes available in various countries, may be useful to government officials in charge of the administration of small water-supply systems.

Depreciation of waterworks equipment is an item which is often ignored by communal authorities. This is always a very poor policy since some important points of the system have a rather short life-expectancy. This is indicated by the yearly depreciation estimates shown in Table IX, which are typical for small systems :

Depreciation should be provided for in the financial structure of the water system, and is an important element in the development of financial plans for future renewal and expansion programmes.

Once sound fiscal methods have been established, it is necessary to ensure that the service bills are being paid. Records showing the list of customers and the amounts of their bills must be kept, together with information

TABLE IX. YEARLY DEPRECIATION ESTIMATES FOR WATERWORKS
SYSTEM IN CLARKSDALE, MISS., USA [20]

Section of waterworks system	Amount of depreciation in percentage of total cost
Reservoir	2
Pumping equipment	4
Treatment equipment	10
Distribution mains and accessories	1.5
Fire hydrants	2
Services	3
Meters	4
Transportation equipment	12
Wells	4

regarding due dates (usually ten days after their issuance). No favours should be granted.

Haley [20] suggests that the administrative and operating procedures of small systems, once established, should be compared with those of other utilities of some size in order to detect hidden defects. He also gives the outlines of three types of financial statements which may be useful in the administration of a small water-supply system. These are reproduced in Annex 8, page 311.

Revenue

Water-supply systems, whether large or small, require funds for their management, operation, and maintenance. The amount of funds usually varies directly with the population served. This is true whether water is distributed through service connexions and meters or through water points and standpipes scattered throughout the village or town. In the former instance, customers often believe that the only investment made to bring them water was the pipe laid in front of their homes and the cost of their meters and service connexions. This is far from the truth and, in developing good public relations, the customers should be brought to understand that the cost of these items represents only a small fraction of the total cost of supply, storage, pumping, treatment, distribution, mains, and hydrants. Sometimes municipality and local government officials need to recognize that it is impossible for a water utility to render satisfactory service and to meet the requirements of future expansion without adequate funds. In some areas, the collection of water fees may conflict with community precedent and with the interests of local groups. It is firmly believed, however, that no matter how poor a community may be, some fee

can and should be collected from the consumers. It has been said that the day when people start to receive water free of charge from a water-supply system marks the beginning of the downfall of the system. This statement, of course, does not apply to a few desert posts or villages on the fringe of desert areas, where water should not be denied to the thirsty traveller and his animals (camels and donkeys). As stated above, no favours should be granted and no exceptions should be made in the collection of water fees. This is the best way of guaranteeing revenues and, therefore, a satisfactory service. Agreement on this issue should be reached with the local government before, not after, construction of the system has started.

Revenues may be raised by the sale of water to consumers, direct appropriation, or a combination of both.

It is important to remember that, as a matter of policy, revenues should provide sufficient funds to pay for all operating and maintenance expenses, the costs of ordinary additions and betterments, and the fixed charges relating to depreciation and interest on long-term debt. If adopted, such a policy in the long run will make it possible to finance major replacements and extensions at least partly from the funds accumulated by the water system itself and at much lower cost, if a new loan must be obtained for these purposes. In many instances, however, communities in rural areas rely, sometimes unduly so, on subsidies from the provincial or central government to finance major replacements and additions. When these are not forthcoming, water service goes from bad to worse and becomes intermittent; and the system deteriorates rapidly, losing all its public health significance.

The sale of water to consumers is by far the preferred method of securing revenue. There are many problems connected with this method, but its important advantages are the following :

(1)   the water-supply administration has direct control over its source of income;

(2)   the needs of the system and water service can be geared to the desires of the consumer who pays for them;

(3)   the consumer has the right and the means to demand service;

(4)   the consumer is more apt to develop a sense of interest and responsibility in the water system's management, operation, and maintenance.

It is realized, however, that in rural areas the proportion of customers paying minimum bills will be rather large, and that the total revenue collected from sale of water is likely to be less than that necessary to meet the above-mentioned requirements.

Additional revenue should be obtained when fire protection is provided by charging both consumers and the community administration for the cost involved. Too often the value of fire protection to the individual and the community is ignored, although the benefit to them is great. In some areas,

a lower cost in fire insurance may result. When expected revenues from water sales are insufficient, a combination of sale of water and direct appropriation may be used. Direct appropriation may involve an *ad valorem* tax for the large-size pipes required, or it may be based on the cost of the portion of, say, a 10- to 15-cm (4- to 6-in.) main assumed to pass in front of each customer's property. This system of taxation is often used with success in some countries, such as the USA.

Water Rates for Service Connexions

In small towns a rate schedule may be designed to apply to the following four classes of consumers :
    (1)   public buildings, schools, and institutions;
    (2)   commercial establishments, such as hotels, industries, etc.;
    (3)   private consumers with house connexions;
    (4)   private consumers supplied through public taps or fountains.

In establishing water rates for small systems, it will be necessary to compile data on expenses for : (*a*) the production of water (costs of labour, chemicals, energy, supplies); (*b*) the distribution of water (costs of labour, operation, maintenance, supplies); (*c*) the administration of the system. These data, together with the information provided by the statistical and financial records previously mentioned, will make it possible to develop a rate schedule which should be reasonable and equitable to the various classes of customers (private houses, public institutions, dairies and markets, commercial establishments, swimming-pools, etc.). The rates should be high enough to provide the necessary revenue, but they should not be so excessive as to discourage customers from making liberal use of the water for domestic needs and for personal hygiene, in particular. Municipally owned systems usually supply water at cost, while privately owned utility companies must sell at a profit.

Rates vary widely among countries as well as within each country. The reader is referred to the interesting studies made by the International Water Supply Association[2] (page 711) and by the American Water Works Association[3] on methods of charging for water. As a rough indication, it may be said here that metered water in small towns is charged at the approximate rate of $0.043 per cubic metre in Brazil (1957),[a] $0.08 per cubic metre in the United Kingdom (1953), $0.075 per cubic metre in Nigeria (1954), $0.06 per cubic metre in the USA (1954), and between $0.07 and $0.14 per cubic metre in Malaya. These rates are for domestic supplies; higher charges are made in some towns for trade and industrial consumption. Furthermore, in some towns additional charges are made for meter rentals, for garden hoses, and for consumption by farm animals.

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[a] Depreciation of system not taken into account.

Paying for Water

In rural towns and villages, especially in underdeveloped countries, a large portion of the population must be supplied with water, for some time to come, through public taps or fountains. It is usually this group which is beset by the most acute public health problems and which, therefore, needs an ample supply of safe water. Yet, the collection of water fees from this segment of the population often raises serious difficulties. W. E. Wood, Chief Water Engineer, Northern Nigeria, has given an interesting and informative assessment of the problem : [a]

" When these consumers are being considered, there are two principal ways of supplying and charging for the water used. Each has its advantages and its drawbacks, and it is not possible to say that either is better in all circumstances.

" One method is that of levying a weekly or monthly water rate on all the inhabitants, except those with private supplies, and to provide water without any further charge through street fountains or standpipes. From an engineering and from a health point of view, this has much to commend it. Standpipes are relatively inexpensive and can be set up in all parts of the town so that water need be carried only a short distance to any house. Water is usually available through the 24 hours. There being no restriction on the amount of water drawn by an individual, every encouragement is given towards cleanliness even in the poorest of properties. The man with a large family (who is usually poorer than the one with fewer children) pays the same amount as the others for his water. A further advantage is that revenue can be accurately estimated and is reasonably constant throughout the year. Against these advantages must be weighed the difficulty of collecting the water rate, particularly with a transient population; the inability to charge casual users who are not rate payers; and the difficulty of controlling waste, which may be of great importance with a limited supply in a dry area. Psychologically, too, there is a greater reluctance to paying a lump sum of thirty units for a month's supply than there is to paying a single unit each day.

" Where it is considered that the disadvantages of this method outweigh the advantages, selling stations are often used. With these, the consumer gets just what he pays for and so is less inclined to waste water. The amount charged per unit of water (in most parts of the world this unit is a kerosene can of about 4 Imperial gallons) is small, and this way of purchasing water is near to the traditional custom of buying from a water-seller which has prevailed for centuries in most tropical countries.

" Selling stations themselves may be simple or elaborate. They vary from a row of standpipes in a simple, fenced enclosure to costly, elaborate structures with surrounding wall, storage tank, an office, and turnstiles for entry and exit. In any case, the necessity for having a collector on duty means that a comparatively large number of people has to be served by each station; this tends to produce congestion during the peak periods of the day, and the fewer number of stations compared with street fountains means a greater distance for water to be carried by many of the purchasers. In order to cope with the periods when draw-off is at its maximum, either larger mains are necessary, or else storage tanks are required at each station to even out the flow. Normally, water is available for sale only during the daylight hours.

" Perhaps the biggest disadvantage of selling stations in areas of distinct wet and dry seasons is the tendency of the poorer people, particularly, to buy water only during the dry season, when water is unobtainable elsewhere, and, during the rains, to collect water

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[a] Personal communication

from contaminated sources such as drainage channels and borrow-pits. Quite apart from the obvious dangers to health of this practice, the revenue in the wet season may drop to a point where it will not even pay for the collector on duty.

" A difficulty which appears trivial at first, but may be a very serious problem, is the question of unit of payment. Undoubtedly the simplest method is charging an exact unit of currency (e.g., one halfpenny) for a four-gallon [18-litre] unit of water. This is a very high amount when translated into bulk supply and is probably four times what a metered consumer would pay, but its chief disadvantage is the difficulty of varying the charge. On the other hand, the issue of tokens or of printed tickets presents its own troubles. Tokens may be worth more in intrinsic value than the amount of money they represent and consequently may be stolen or used for other purposes; and tickets have to be printed and sold and then are liable to counterfeiting. An organization is also necessary for the sale of these tickets or tokens.

" The design and arrangement of selling stations will depend largely on the way they are to be operated. Sometimes they are operated by the local authority; but more frequently they are let out to contractors. In large towns the bulk of the stations are occasionally put out to contract, while the local authority keeps a few stations as a control.

" Contracting is the favourite method because the onus of collecting payment and checking the honesty of the collectors is on the contractor who pays for the total water supplied to the station through a meter and who sells at a price controlled by the water authority. Naturally the contractor keeps waste to a minimum and ensures that payment is properly made; but, equally naturally, he requires a return for his trouble and for the wages of his staff, and so he is reluctant to operate a station in a sparsely populated section of the town. Stations under contractors, therefore, tend to be few in number, each catering for a large population; and, under these conditions, a contractor will often pay a substantial premium in advance for the privilege of operating one or more stations. It is usual for contracts to be for six months' or a year's duration, and for tenders to be called for when new contracts are due.

" When a local-authority employee operates a station on behalf of the authority, the theory is that water consumption is checked by meter and the operator collects from the consumers a total amount equal to the price of the water supplied. It is found in practice, unfortunately, that there is usually a considerable discrepancy between the two figures; and an authority which starts off with ' direct ' sales may find with experience that a contractor is a more reliable source of income.

" The simplest type of selling station consists of barbed wire surrounding a row of standpipes, the area within the enclosure being concreted and drained, with an entrance and exit on either side of a small shelter in which the collector sits. The fence may be continued outwards to enclose a queue of waiting consumers during peak hours.

" A second type consists of a small, enclosed shelter or booth, the upper part of which is of wire mesh. A shelf at a convenient height extends across the front of this booth with room for four kerosene tins. These tins are filled from spouts above the shelf, each spout being supplied through a stopcock situated inside the booth and operated by the collector after the appropriate money has been paid.

" In a large station suitable for local-authority operation, entry and exit are by recording turnstile; and a storage tank ensures that a large number of people can be served in a short time at any hour of the day, even though pumping may be intermittent.

" Selling stations may also be incorporated with other sanitary structures, such as public baths, laundries, etc. ".

Chapter 11

OPERATION AND MAINTENANCE

General Considerations

The nature and scope of the operation and maintenance required will vary with the design and elements of water-supply systems. Depending upon the particular situation, the field work may include :

(1) well, spring, or drainage basin inspection and maintenance;

(2) dam and reservoir maintenance;

(3) pump and engine operation and maintenance;

(4) treatment operation;

(5) distribution system maintenance;

(6) service connexions to system;

(7) meter repairs and maintenance;

(8) operation in emergencies;

(9) detection and elimination of cross-connexions.

Some information has already been given under the relevant sections regarding the principal features of operation and maintenance of various elements of water systems. This will not be repeated here; but some additional points of interest to waterworks field personnel are described in Annex 9 (see page 313).

There are two principal factors which contribute to most failures in water systems : (a) equipment and materials used under conditions for which they were not designed; and (b) operators who, because of either ignorance or disinterest, do not recognize the signs which precede or portend breakdowns and failures. By careful review of plans, design, and specifications, the water-supply-control administration can succeed in preventing or eliminating most difficulties of a mechanical character. The reduction of troubles caused by the human element is perhaps harder to achieve; but much can be done, as previously indicated, through training of field personnel, assistance from outside qualified staff (a form of in-service training) and close supervision.

Equipment

For small water systems, the following suggestions may be made :

(1) Manufacturers' recommendations as to operation and maintenance procedures should be scrupulously observed. They should be drafted into

a form which can be easily understood by the operators. This is especially important with regard to pumping machinery.

(2) Maintenance should be organized according to rigid schedules. This applies to operations such as greasing, oiling, inspections, adjustments, and minor repairs.

(3) A system of supervision should be established to ensure that procedures and schedules are followed.

(4) Lubrication recommendations by the manufacturer of a particular piece of equipment must be followed.

(5) Ample space must be provided for equipment operators or maintenance men to work and to keep tools, spare parts, oil, grease and other supplies.

(6) Provision must be made for the establishment of suitably equipped workshops.

The following major field equipment will be found useful in most instances (depending upon the scope of the water system) :

(1) dump truck(s), for the transportation of pipes smaller than 25 cm (10 in.) in size;

(2) an air compressor, pavement breakers, and air hammers;

(3) ditch pumps (at least two of them) equipped with 3.6-m (12-ft) hoses, for keeping trenches dry during work;

(4) electric generators, with two floodlights and extension cords, for emergency work at night;

(5) a small crane, handling up to about 2.5 metric tons (3 tons), equipped with pneumatic tires and a ball-bearing swivel safety hook and capable of 180° turning capacity. A crane is not needed for handling pipes of less than 15 cm (6 in.) in diameter, but is useful for handling, turning, and lowering pipes of larger diameter. Handling large pipes with hand labour and ropes usually results in an undue amount of breakage of pipe joints.

Distribution System

First and foremost, the operation and maintenance of a distribution system require the establishment of system maps and records. The system map should be drawn on large scale, preferably not less than 1 : 10 000, and should show all streets and their names, mains and their sizes and locations, valves and hydrants, reservoirs and elevated tanks, supply sources, and any other useful information. Besides the making of at least one full map, the same map may be divided into sections and bound for easy handling in the field.

In addition to the system map, valve records are necessary (except in very small water-supplies) to show their exact location, their numbering, and any particular reference regarding their operation. These records

can take the form of separate large-scale drawings, each for one valve, entered in a loose-leaf binder for handy reference. A system should be devised to ensure that these records and the maps are kept up to date. This is facilitated if pertinent information is reported and recorded after each repair or maintenance job is performed. These records are especially useful whenvalve boxes and cones are hidden or " lost ", having been covered in the course of street repairs or construction.

The following specific suggestions may apply :

(1) *Valves*: Their function and installation are described in a previous section (see page 205). Valves and hydrants (if any) should be inspected every two months. This should be a primary duty of field operators and should be carried out on a regular inspection schedule using a simple check list to ensure that no valve is missed. The effort spent will repay itself many times in cases of emergency and fire when valves must be located and operated quickly. Packing and leakage can also be checked at inspection time.

(2) *Piping*: The maintenance of distribution pipes consists in checking for leaks, corrosion, and scale. Each time a line is opened, the interior of the piping can be observed. The life of more than one system has been greatly extended by workmen who have reported pipe damage when making a house connexion.

(3) *Tanks*: Concrete tanks require very little attention, while steel tanks must be painted often to prevent damage from corrosion. Instructions of manufacturers regarding type of paints and methods for painting must be closely followed.

(4) *Meters*: Meters usually require much attention. An organized maintenance system must be set up, or else the whole metering process will soon fail. A small repair shop is required for the cleaning and testing of meters and for the replacement of worn-out parts. It can be a room about 4×5 m (13×17 ft), equipped with benches, small tools, water connexions, gauges, etc. It need not be complex and may be run by from one to four trained persons. A well-equipped repair shop manned by four experienced workmen can handle up to 5000 ordinary service meters a year.

Cross-Connexions

In small community water-systems, many opportunities exist for direct cross-connexions between public water-supplies and private cisterns and wells. Also, there is the always-present danger of back-siphonage of contaminated water from lavatory washbasins, water-closets, etc., into public distribution pipes when the domestic plumbing systems are not properly built. Furthermore, it does happen sometimes that the positive pressure existing in a main pipe drops suddenly to nil, or even becomes negative,

because of an accident, fire demand, leaking valves, or some human error of operation. Sanitary engineers are very familiar with the different types of cross-connexion and with the public health hazards associated with them. Many water-borne epidemics caused by accidental cross-connexions are reported in the literature. The field personnel of small water-systems should be alert to the danger and, although they are usually not responsible for inspection of house plumbing, the field service should be prepared to advise and assist customers in eliminating such plumbing defects.

Cross-connexions should be expressly forbidden. However, special requests from industries or neighbouring public water systems, for example, for connexions of their water pipes with the town's distribution system should be closely examined by competent public health or water engineers on behalf of, or attached to, the controlling health administration. Wherever possibilities exist for back-siphonage, a free-fall discharge of the town's water should be observed. It is generally agreed that a free fall equal to at least two pipe diameters above the highest flood level of the receiving unit is safe. In the case of lavatory washbasins, the maximum flood level would be the top of the basin, even though an overflow pipe is provided. Vacuum breakers are also used to prevent back-siphonage. They are usually installed at least 10-15 cm (4-6 in.) above the maximum flood level of the receiving unit, according to manufacturers' instructions. Special devices, such as the back-flow preventer, must be approved by the public health administration before they can be installed in a system linking private and public water-supplies.

Operation in Emergencies

Every public water-system, whether large or small, should be as prepared as possible for emergency operating procedures which may be necessitated by such catastrophes as earthquake, flood, war damage, or evacuation of populations due to war or sudden cataclysms. It must be remembered that, in such circumstances, water is probably the most urgent need of individuals, who will use any available source, polluted or not, with the consequent hazards of epidemics, if provision is not made quickly for a supply of safe water. In fact, the amount of water available may govern the number of evacuees who may be received and handled in a particular village or town. For this reason, it is recommended that, soon after the start of operation of a new water-system, or even before, a realistic inventory be made covering all available sources of water supplies, public or private, together with their capacities, location, accessibility and potability. This inventory should also include personnel resources and available, emergency type, water-supply equipment, hand and motor pumps, water-tank trucks, pipe accessories (especially coupling and jointing materials), mobile or

portable filter units, tools, spare parts, and chemicals (especially those for water disinfection purposes).

At times of emergencies, a minimum of 1 litre (1 qt) of water should be provided daily for drinking only and another 3 litres (3 qt) for other purposes, in such places as temporary shelters. In camps with tents, a minimum of 20 litres (5 US gal.) should be provided, and this amount should be doubled for the supply of temporary hospitals and first-aid stations. It goes without saying that every step should be taken to conserve water, and that every possible sanitary safeguard should be employed to protect existing supplies—especially surface supplies such as lakes, ponds, open reservoirs, and springs—from contamination. While ground-water supplies from properly constructed wells, infiltration galleries, and spring structures may sometimes be considered safe, all surface water should be considered of doubtful quality and should be disinfected by boiling, chlorination, or disinfection by iodine compounds. The notes previously given under " Household purification of water " (see page 185) also apply here, except that heavier chlorination is recommended. The free chlorine residual in reasonably clear water at times of emergencies should be not less than 5 p.p.m. after 30 minutes of contact [38] when the water has not had the benefit of prior filtration. The raw water should be taken from an approved source; and, if it has strong taste, odour, or colour, it should be avoided as far as possible.

Chapter 12

LONG-TERM PLANNING

As stated earlier (see page 227), one of the main functions of management is the development of technical and financial plans for future expansion. Every water system, whether large or small, should periodically review its present adequacy and its future requirements.

First, it is necessary to analyse the ability of the system to deliver water of adequate quality and quantity, under sufficient pressures, at times of maximum demand. The forecast of future requirements will then involve the determination of the area and population to be served and the future total consumption. With a sound financial policy which provides for accumulation of depreciation reserve, it is possible to co-ordinate construction and financing and to make them both simpler and more economical than they would otherwise be. It is worth remembering that it is much better to keep up and improve the system through small construction programmes undertaken yearly than to allow deficiencies to accumulate and needs to become acute. These yearly improvements, however, should be planned to fit in with ultimate objectives and requirements.

The elaboration of technical plans for future expansion requires a thorough knowledge of the original design and basis for the water system. As a rule, such plans should be submitted to the public health administration for review and approval by its public health (sanitary) engineering department—when, of course, they are not prepared by this department itself.

In addition, the planning engineers and government officials should not lose sight of the possibilities of integrating individual village systems within a broader district or regional water-supply scheme. In analysing the principles which should guide long-range planning for water service, Wolman[46] has stated:

" One of the major characteristics of water supply service in the past has been, with some important exceptions, that it has been confined largely to the development and extension of water service within limited political boundaries—usually those of the familiar municipality... Orthodox water planning, geared to restricted geographical areas, and to the considerations of earlier decades, has inhibited more imaginative solutions. The traditional political boundary has, perhaps, played an unfortunate part in restraining water service—whether the service was publicly or privately owned. An awareness of these realities is a prerequisite to solving problems which new and unexpected demands have posed. "

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ANNEXES

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Annex 2

CONVERSION FACTORS

Length

Inch (in.) = 2.54 cm
Foot (ft) = 12 in. = 30.48 cm
Yard (yd) = 3 ft = 0.9144 m
Mile = 5280 ft = 1.609 km
Centimetre (cm) = 0.3937 in.
Metre (m) = 100 cm = 3.281 ft = 1.0936 yd
Kilometre (km) = 1000 m = 0.6214 mile

Area

Square inch (sq. in.) = 6.452 cm^2
Square foot (sq. ft) = 144 sq. in. = 929.0 cm^2
Acre = 43 560 sq. ft = 0.4047 ha
Square mile (sq. mile) = 640 acres = 2.590 km^2
Square centimetre (cm^2) = 0.1550 sq. in.
Square metre (m^2) = 10 000 cm^2 = 10.764 sq. ft
Hectare (ha) = 10 000 m^2 = 2.471 acres
Square kilometre (km^2) = 100 ha = 0.3861 sq. mile

Volume and capacity

Cubic inch (cu. in.) = 16.387 cm^3 or ml
Cubic foot (cu. ft) = 1728 cu. in. = 28.316 l = 6.229 Imp. gal. = 7.481
    US gal.
Cubic yard (cu. yd) = 27 cu. ft = 0.7646 m^3
Fluid ounce (British) (fl. oz.) = 28.41 ml
    —   (US) (US fl. oz.) = 29.57 ml
Pint (British) (pt) = 20 fl. oz. = 0.5682 l
 — (US) (US pt) = 16 US fl. oz. = 0.4732 l
Quart (British) (qt) = 2 pt = 1.1365 l
    —   (US) (US qt) = 2 US pt = 0.9463 l
Imperial gallon (British) (Imp. gal.) = 277.42 cu. in. = 1.2009 US gal.
    = 4.546 l
US gallon (US gal.) = 231.0 cu. in. = 0.8327 Imp. gal. = 3.785 l
Acre-foot = 1233.5 m^3

17

Cubic centimetre (cm³) = 0.999972 ml = 0.06102 cu. in.
Millilitre (ml) = 1.000028 cm³ = 0.03520 fl. oz.
Litre (l) = 1000 ml = 0.2200 Imp. gal. = 0.2642 US gal. = 0.035316 cu. ft
Cubic metre (m³) = 1000.028 l = 1.3080 cu. yd = 220.0 Imp. gal. = 264.2
    US gal. = 0.0008107 acre-foot

Weight

Grain = 0.06480 g
Ounce (oz.) = 437.5 grains = 28.35 g
Pound (lb.) = 16 oz. = 0.45359 kg
Stone = 14 lb. = 6.350 kg
Hundredweight (cwt) (British) = 112 lb. = 50.802 kg
    —   — (US) = 100 lb. = 45.359 kg
(Long) ton (British) = 2240 lb. = 1.01605 t
Short ton (US) = 2000 lb. = 0.90718 t
Gram (g) = 15.432 grains
Kilogram (kg) = 1000 g = 2.2046 lb.
Metric ton (t) = 1000 kg = 0.9842 long ton = 1.1023 short tons

Pressure

Pound per square inch (p.s.i.) = 0.06805 atm. = 0.07031 kg/cm² = 0.7031 m
    of water = 2.307 ft of water
Standard atmosphere (atm.) = 14.696 p.s.i. = 1.0332 kg/cm²
Metric atmosphere (kg/cm²) = 14.223 p.s.i. = 0.9678 atm.

Flow rate

Cubic foot per second (cu. ft/sec) = 0.5382 mgd (Imp.) = 0.6463 mgd (US)
Cubic foot per minute (cu. ft/min.) = 0.4719 l/sec
Imperial gallon per minute (Igpm) = 0.07577 l/sec = 0.2728 m³/h
US gallon per minute (gpm) = 0.06309 l/sec = 0.2271 m³/h
Million gallons per day (mgd) (Imperial) = 52.615 l/sec
    —   —   —   — (US) = 43.811 l/sec
Litre per second (l/sec) = 3.6001 m³/h = 13.20 Igpm = 15.85 gpm =
    0.019006 mgd (Imp.) = 0.022825 mgd (US)
Cubic metre per hour (m³/h) = 0.2778 l/sec = 3.666 Igpm = 4.403 gpm

Filtration rate

Million Imperial gallons per acre per day (mgad, Imp.) = 1.1234 m³/m²/day
Million US gallons per acre per day (mgad) = 0.9354 m³/m²/day
Cubic metre per square metre per day (m³/m²/day) = 1.0691 mgad =
    0.8902 mgad (Imp.)

Miscellaneous

Horsepower (h.p.) = 33 000 foot-pounds per minute = 0.746 kW = 1.0139 CV

Kilowatt (kW) = 1.36 CV = 1.34 h.p.

Cheval-vapeur (CV) = 0.9863 h.p. = 0.736 kW

One litre of water weighs one kilogram (at 4°C)

One cubic foot of water weighs 62.43 pounds

One US gallon of water weighs 8.345 pounds.

Annex 3

FLOW MEASUREMENTS *

Measuring Flow of Water in a 60° V-Notch Weir

NOTE:

Over and under baffles, set 4 in. below top and 4 in. above floor of channel respectively, are to create stilling basins.

Rule or measuring stick may be nailed on inside of box with zero point of rule set the same distance off the channel floor as the notch in the weir plate.
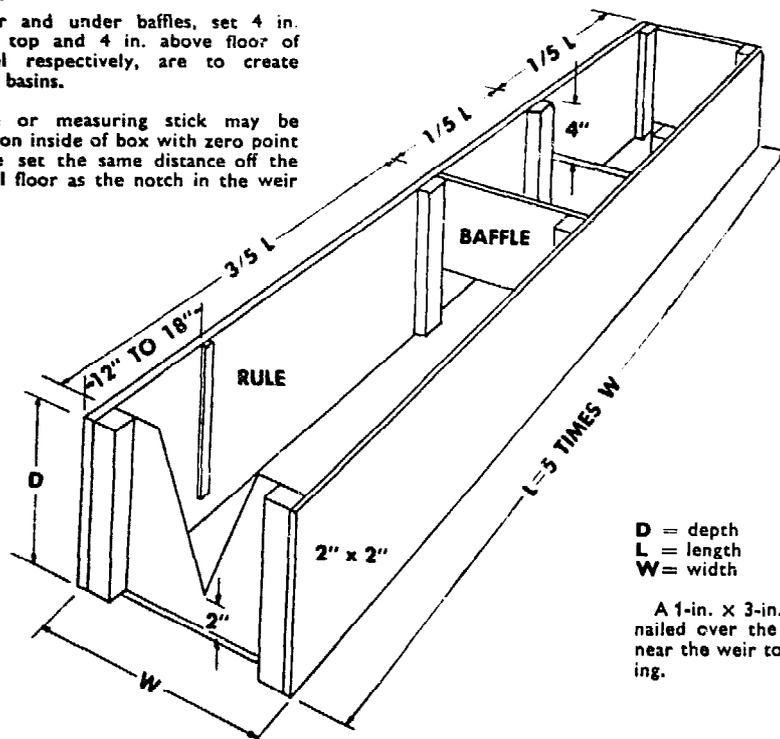
D = depth
L = length
W = width

A 1-in. × 3-in. board should be nailed over the top of the box near the weir to prevent spreading.

The box should be constructed of 1-in. lumber and all cracks should be made watertight. The underflow baffle could be made so that it could be adjusted in height off the floor as needed to prevent disturbance of the water surface at the weir. The weir plate should be heavy-gauge metal backed with 1-in. lumber.

Care should be taken to shore up the box so that the weight of the water will not cause structural failure. 2-in. × 4-in. × 4-in. timbers could be nailed to the under-side of the box with the ends extending to be used as handles.

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* From US War Department (1945) *Military water supply and purification*, Washington, D.C. (War Department Technical Manual TM 5-295) by kind permission.

The structure should be carefully levelled both ways before taking depth-of-flow readings. The box should be filled with water to same elevation as notch in weir. The zero end of measuring rule should touch water surface.
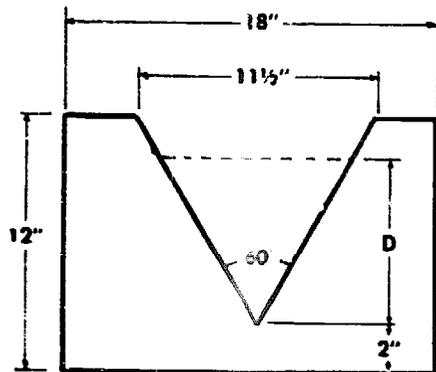
FLOW IN G.P.M.* PER $\frac{1}{4}$ IN. OF DEPTH

D	G.P.M	D	G.P.M
$\frac{1}{2}$	0.25	$4\frac{1}{2}$	57.9
$\frac{3}{4}$	0.69	$4\frac{3}{4}$	66.2
1	1.41	5	75.2
$1\frac{1}{4}$	2.45	$5\frac{1}{4}$	84.7
$1\frac{1}{2}$	3.84	$5\frac{1}{2}$	95.1
$1\frac{3}{4}$	5.61	$5\frac{3}{4}$	106.1
2	7.84	6	117.9
$2\frac{1}{4}$	10.45	$6\frac{1}{4}$	130.3
$2\frac{1}{2}$	13.60	$6\frac{1}{2}$	143.7
$2\frac{3}{4}$	17.17	$6\frac{3}{4}$	157.6
3	21.29	7	172.4
$3\frac{1}{4}$	25.92	$7\frac{1}{4}$	188.1
$3\frac{1}{2}$	31.15	$7\frac{1}{2}$	204.4
$3\frac{3}{4}$	36.89	$7\frac{3}{4}$	221.8
4	43.31	8	239.7
$4\frac{1}{4}$	50.27		

Discharge Over a Rectangular Weir Per Foot Width in US Gallons **

(See fig. overleaf)

Depth (in.)	Gallons per minute	Depth (in.)	Gallons per minute	Depth (in.)	Gallons per minute
1	36	$4\frac{3}{4}$	375	$8\frac{1}{2}$	900
$1\frac{1}{4}$	50	5	405	$8\frac{3}{4}$	939
$1\frac{1}{2}$	66	$5\frac{1}{4}$	436	9	978
$1\frac{3}{4}$	84	$5\frac{1}{2}$	468	$9\frac{1}{4}$	1 020
2	102	$5\frac{3}{4}$	500	$9\frac{1}{2}$	1 062
$2\frac{1}{4}$	122	6	533	$9\frac{3}{4}$	1 104
$2\frac{1}{2}$	143	$6\frac{1}{4}$	567	10	1 147
$2\frac{3}{4}$	165	$6\frac{1}{2}$	601	$10\frac{1}{4}$	1 190
3	188	$6\frac{3}{4}$	636	$10\frac{1}{2}$	1 234
$3\frac{1}{4}$	212	7	672	$10\frac{3}{4}$	1 279
$3\frac{1}{2}$	237	$7\frac{1}{4}$	708	11	1 323
$3\frac{3}{4}$	263	$7\frac{1}{2}$	745	$11\frac{1}{4}$	1 369
4	290	$7\frac{3}{4}$	783	$11\frac{1}{2}$	1 414
$4\frac{1}{4}$	317	8	821	$11\frac{3}{4}$	1 461
$4\frac{1}{2}$	346	$8\frac{1}{4}$	860	12	1 508

NOTE. Not accurate when depth of flow over weir exceeds one-third width of weir.

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* US gal. per minute.

** This table applies only to rectangular weir with end contractions as shown.
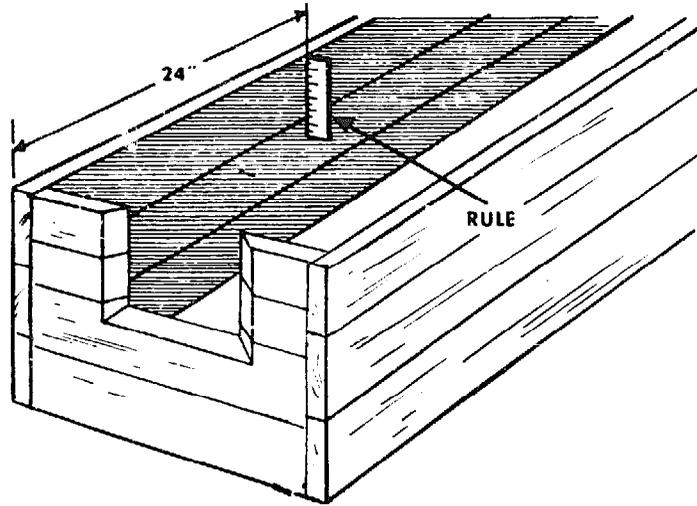
Flow of Vertical Jets in US Gallons Per Minute

Height of jet (in.)	Diameter of pipe or hose (in.)			
	1	1½	2	3
½	3.96	8.9	15.6	35.6
1	5.60	12.6	22.4	50.4
2	7.99	18.0	32.0	71.9
4	11.3	25.4	45.3	102
6	13.9	31.3	55.5	125
8	16.0	36.0	64.0	144
10	17.9	40.3	71.6	161
15	22.0	49.5	87.8	198
20	25.4	57.2	102	228
30	30.9	69.5	123	278
60	43.8	98.6	175	394
108	58.9	132.5	236	531
144	68.0	153.0	272	612
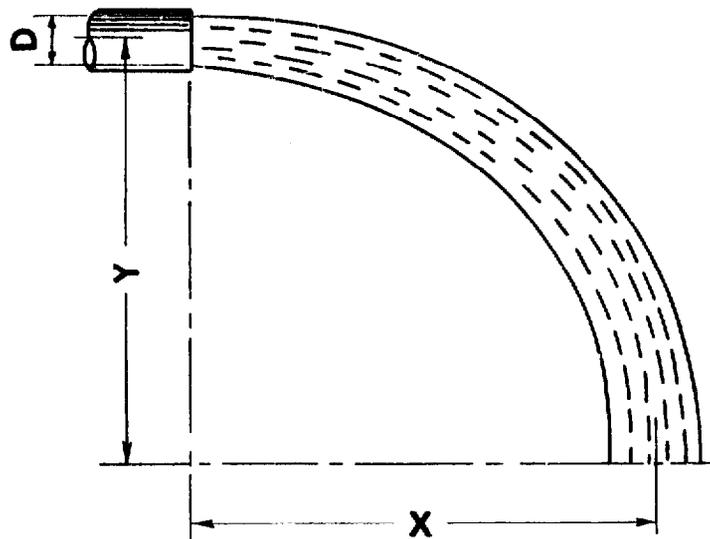
Flow of Water from Full-Flowing Horizontal Jets

NOTE. Jet must be full-flowing; no contraction or enlargement.

$$\text{Flow in US g.p.m.} = \frac{2.83 \cdot D^2 \cdot X}{\sqrt{Y}}$$

$D =$ Inside diameter of pipe
$X =$ Horizontal distance in inches
$Y =$ Vertical distance in inches

Example using formula :

Given : A 3-in.-diameter standard pipe ($D = 3.07$ in.) held 16 in. from ground ($Y = 16$ in.). X determined by measurement ($X = 28$ in.)

$$\frac{2.83 \cdot 3.07^2 \cdot 28}{\sqrt{16}} = \frac{2.83 \cdot 9.4 \cdot 28}{4} = 187 \text{ g.p.m.}$$

NOTE. Table below is based on $Y = 12$ in. When table does not apply, measure Y at 9 in., 16 in., or 25 in. for simplicity in taking square root.

US g. p. m. for Y = 12 in. and various values of X

Distance X (in inches) =	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
D = 1.61 in. 1½ in. standard pipe	17	21	25	30	34	38	42	47	51	55	59	64	68	72	76	80	85	89	93	97	102
D = 2.07 in. 2 in. standard pipe	28	35	42	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154	160	167
D = 4.03 in. 4 in. standard pipe	106	132	159	185	212	238	265	291	318	344	371	397	424	450	477	503	530	556	583	609	656

Friction of Water in Pipes *

The friction head losses in pipes were derived using the William & Hazen coefficient of 100. This coefficient corresponds to 10-year-old steel or 18-year-old cast-iron pipe. To adjust the friction head loss for various types of pipe, use the factor below. For example: To find the friction head loss for *3-in. iron pipe with very rough inside surface*, passing 50 g.p.m., find 13.8 ft per 1 000 ft of pipe in table and multiply by 2.58. Answer: 35.6 ft friction head loss per 1000 ft of *3-in. iron pipe with very rough inside surface*.

Kind of pipe :   Factor

New cast-iron (straight) 0.540

New lead or brass 0.540

New concrete or masonry (very smooth) 0.540

New cast-iron (not straight) 0.615

Smooth concrete or masonry 0.615

New wrought-iron (smooth) 0.715

Cast-iron (5 years old) 0.715

Wood (smooth) 0.715

New rivet-steel 0.840

Vitrified sewer 0.840

Cast-iron (30 years old) 1.51

Old wrought-iron 1.51

Small wrought-iron (over 15 years old) 1.51

Iron with very rough inside surface 2.58

Gallons per minute	Gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
½-in. pipe (0.623 in. inside diameter)				
1	1 440	1.05	0.02	21.0
2	2 880	2.10	0.07	74.0
3	4 320	3.16	0.16	158.0
4	5 760	4.21	0.28	270.0
5	7 200	5.26	0.43	410.0
6	8 640	6.31	0.61	570.0
7	10 080	7.37	0.84	760.0
8	11 520	8.42	1.10	980.0
9	12 960	9.47	1.40	1 210.0
10	14 400	10.52	1.70	1 470.0

* US gallons are used in this table.

Gallons per minute	Gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe

¾-in. pipe (0.824 in. inside diameter)

Gallons per minute	Gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
2	2 880	1.20	0.02	19.0
3	4 320	1.80	0.05	41.0
4	5 760	2.41	0.09	70.0
5	7 200	3.01	0.15	105.0
6	8 640	3.61	0 20	147.0
8	11 520	4.81	0.37	250.0
10	14 400	6.02	0.56	380.0
12	17 280	7.22	0.80	530.0
15	21 600	9.02	1.26	800.0
20	28 800	12.03	2.24	1 360.0

1-in. pipe (1.04 in. inside diameter)

Gallons per minute	Gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
3	4 320	1.12	0.02	12.6
4	5 760	1.49	0.03	21.4
5	7 200	1.86	0.05	32.5
6	8 640	2.23	0.07	45.5
8	11 520	2.98	0.14	78.0
10	14 400	3.72	0.22	117.0
12	17 280	4.46	0.30	164.0
14	20 160	5.20	0.45	220.0
16	23 040	5.95	0.55	280.0
18	25 920	6.69	0.70	350.0
20	28 800	7.44	0.87	420.0
25	36 000	9.30	1.34	640.0
30	43 200	11.15	1.93	890.0
35	50 400	13.02	2.65	1 190.0
40	57 600	14.88	3.42	1 520.0

US gallons are used in this table.

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
1½-in. pipe (1.61 in. inside diameter)				
4	0.00576	0.63	0.01	2.6
6	0.00864	0.94	0.01	5.6
8	0.0115	1.26	0.02	9.5
10	0.0144	1.57	0.04	14.3
12	0.01728	1.89	0.05	20.1
14	0.0202	2.20	0.06	26.8
16	0.0230	2.52	0.10	34.1
20	0.0288	3.15	0.15	52.0
25	0.0360	3.96	0.24	78.0
30	0.0432	4.72	0.38	110.0
35	0.0504	5.51	0.47	147.0
40	0.0576	6.30	0.61	188.0
45	0.0648	7.08	0.77	232.0
50	0.0720	7.87	0.97	284.0
60	0.0864	9.44	1.38	396.0
70	0.101	11.02	1.87	530.0
80	0.115	12.59	2.48	680.0
90	0.130	14.17	3.12	840.0
100	0.144	15.74	3.84	1 020.0
120	0.173	18.89	5.51	1 430.0
140	0.202	22.04	7.60	1 900.0
2-in. pipe (2.00 in. inside diameter)				
6	0.00864	0.61	0.01	2.0
10	0.0144	1.02	0.02	5.0
15	0.0216	1.54	0.04	10.8
20	0.288	2.04	0.06	18.2
25	0.0360	2.55	0.10	27.3
30	0.0432	3.06	0.15	38.4
35	0.0504	3.57	0.20	51.0
40	0.0576	4.08	0.26	66.0
50	0.0720	5.11	0.40	99.0
60	0.0864	6.13	0.58	139.0

US gallons are used in this table.

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe

2-in. pipe (*continued*)

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
70	0.101	7.15	0.79	184.0
80	0.115	8.17	1.04	237.0
90	0.130	9.19	1.31	294.0
100	0.144	10.21	1.62	358.0
120	0.173	12.25	2.33	500.0
140	0.202	14.30	3.17	670.0
160	0.230	16.34	4.14	860.0
180	0.259	18.38	5.23	1 070.0
200	0.288	20.42	6.46	1 290.0
220	0.316	22.47	7.82	1 540.0
240	0.345	24.51	9.31	1 820.0
260	0.374	26.55	10.90	2 110.0

3-in. pipe

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
10	0.01440	0.45	0.00	0.7
15	0.02160	0.68	0.01	1.5
20	0.02880	0.91	0.01	2.5
30	0.04320	1.36	0.03	5.4
40	0.05760	1.82	0.05	9.10
50	0.07200	2.27	0.08	13.8
60	0.08640	2.72	0.12	19.2
70	0.10080	3.18	0.16	25.7
80	0.11520	3.63	0.20	32.8
90	0.12960	4.09	0.26	40.8
100	0.14400	4.54	0.32	49.6
120	0.17280	5.45	0.46	70.0
140	0.20160	6.35	0.63	92.0
160	0.23040	7.26	0.82	118.0
180	0.25920	8.17	1.04	148.0
200	0.28800	9.08	1.28	178.0
220	0.31680	9.99	1.55	213.0
240	0.34560	10.89	1.84	251.0
260	0.37440	11.80	2.16	291.0
280	0.40320	12.71	2.51	334.0

US gallons are used in this table.

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
3-in. pipe (*continued*)				
300	0.43200	13.62	2.88	380.0
320	0.46080	14.52	3.28	428.0
340	0.48960	15.43	3.71	479.0
360	0.51840	16.34	4.15	530.0
380	0.54720	17.25	4.62	590.0
400	0.57600	18.16	5.11	650.0
420	0.60480	19.06	5.64	710.0
440	0.63360	19.97	6.20	770.0
460	0.66240	20.88	6.78	840.0
480	0.69120	21.79	7.38	910.0
500	0.72000	22.70	8.00	980.0
550	0.79200	24.96	9.70	1 170.0
600	0.86400	27.23	11.50	1 370.0
4-in. pipe				
20	0.02880	0.51	0.00	0.62
30	0.04320	0.77	0.01	1.32
40	0.05760	1.02	0.02	2.23
50	0.07200	1.28	0.03	3.39
60	0.08640	1.53	0.04	4.72
70	0.10080	1.79	0.05	6.3
80	0.11520	2.04	0.06	8.1
100	0.14400	2.55	0.10	12.2
120	0.17280	3.06	0.15	17.1
140	0.20160	3.57	0.20	22.8
160	0.23040	4.08	0.26	29.1
180	0.25920	4.60	0.33	36.1
200	0.28800	5.11	0.41	44.0
220	0.31680	5.62	0.49	52.0
240	0.34560	6.13	0.58	62.0
260	0.37440	6.64	0.69	72.0
280	0.40320	7.15	0.79	82.0
300	0.43300	7.66	0.91	93.0
320	0.46080	8.17	1.04	105.0
340	0.48960	8.68	1.17	117.0

US gallons are used in this table.

Gallons per minute	Million gallons per 24 hours	Velocity, feet per second	Velocity, head in feet	Friction in feet per 1000 feet of pipe
		4-in. pipe (*continued*)		
360	0.51840	9.19	1.31	131.0
400	0.57600	10.21	1.62	160.0
450	0.64800	11.49	2.05	198.0
500	0.72000	12.77	2.53	240.0
600	0.86400	15.32	3.65	337.0
700	1.00800	17.87	4.96	449.0
800	1.15200	20.42	6.48	570.0
900	1.29600	22.98	8.20	710.0
		6-in. pipe		
35	0.050	0.39	0.00	0.25
50	0.072	0.57	0.00	0.47
100	0.144	1.14	0.02	1.4
150	0.216	1.71	0.05	3.2
200	0.288	2.28	0.08	6.2
250	0.360	2.80	0.12	9.2
300	0.432	3.40	0.18	12.9
350	0.504	3.98	0.24	17.5
400	0.576	4.54	0.32	22.1
450	0.648	5.12	0.41	26.5
500	0.720	5.60	0.49	33.0
550	0.792	6.16	0.59	39.3
600	0.864	6.72	0.70	47.0
650	0.936	7.28	0.82	54.0
700	1.008	7.84	0.96	62.0
750	1.080	8.50	1.13	70.0
800	1.152	9.08	1.28	80.0
850	1.224	9.58	1.42	89.5
900	1.296	10.30	1.64	101.1
1 000	1.440	11.32	1.99	120.4
1 100	1.584	12.50	2.44	143.1
1 200	1.728	13.52	2.86	166.9
1 300	1.872	14.7	3.4	202.0
1 400	2.016	16.0	3.97	225.0
1 500	2.160	17.0	4.54	259.0

US gallons are used in this table.

Resistance of Valves and Fittings *

Size of pipe (small diameter), in inches	Standard elbow	Medium radius elbow	Long radius elbow	45° elbow	Tee	Return bend	Gate valve open	Globe valve open	Angle valve open
	Length of straight pipe giving equivalent resistance to flow								
½	1.5	1.4	1.1	0.77	3.4	3.8	0.35	16	8.4
¾	2.2	1.8	1.4	1.0	4.5	5.0	0.47	22	12.0
1	2.7	2.3	1.7	1.3	5.8	6.1	0.6	27	15.0
1¼	3.7	3.0	2.4	1.6	7.8	8.5	0.8	37	18.0
1½	4.3	3.6	2.8	2.0	9.0	10.0	0.95	44	22.0
2	5.5	4.6	3.5	2.5	11	13.0	1.2	57	28.0
2½	6.5	5.4	4.2	3.0	14	15.0	1.4	66	33.0
3	8.1	6.8	5.1	3.8	17	18.0	1.7	85	42.0
3½	9.5	8.0	6.0	4.4	19	21.0	2.0	99	50.0
4	11.0	9.1	7.0	5.0	22	24.0	2.3	110	58.0
5	14.0	12.0	8.9	6.1	27	31.0	2.9	140	70.0
6	16.0	14.0	11.0	7.7	33	37.0	3.5	160	83.0
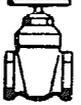
* When the length of pipe is greater than 1000 times its diameter, the loss of head due to valves and fittings may be disregarded.

Annex 4

COLLECTION OF WATER SAMPLES *

Bacteriological Tests

Scrupulous care in the collection of samples for bacteriological examination is necessary to ensure that the sample is representative of the water under examination and to avoid accidental contamination of the sample during collection.

When several samples are collected on the same occasion from the same source, the sample for bacteriological examination should be taken first, to avoid the danger of contamination of the sampling point during the collection of others.

Sample containers

Sterilized (neutral) glass bottles provided with ground-glass stoppers should be used for collection of samples for bacteriological examination. The stopper and neck of the bottle should be protected by a paper or parchment cover, or by thin aluminium foil.

If the water to be sampled contains, or is likely to contain, traces of residual chlorine or chloramine, it is necessary to add to the sampling bottle, before sterilization, a sufficient quantity of sodium thiosulfate ($Na_2S_2O_3$, $5H_2O$) to neutralize these substances. It has been shown that 0.1 ml of a 3% solution of crystalline sodium thiosulfate (3.0 mg) in a 170-ml bottle has no significant effect on the coliform or *Escherichia coli* content of unchlorinated water during storage. This proportion of sodium thiosulfate is sufficient to neutralize more than 5 mg/litre of residual chlorine. It is therefore recommended that this proportion of sodium thiosulfate solution be added to all bottles used for the collection of samples for bacteriological examination. When samples of chlorinated water are taken, it is desirable to determine the content of residual chlorine at the sampling point.

Sampling procedures

The sampling bottle should be kept unopened until the moment at which it is required for filling. The stopper should be removed with care to eliminate soiling, and during sampling the stopper and neck of the

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* After World Health Organization (1958) *International standards for drinking-water*, Geneva, pp. 16, 25

bottle should not be handled and should be protected from contamination. The bottle should be held near the base; it should be filled without rinsing; and the stopper should be replaced immediately.

If a sample of water is to be taken from a tap on a distribution system, it should be ascertained that the tap chosen is supplying water from a service pipe directly connected with the main, and not, for instance, one served from a cistern or storage tank. The tap should be cleaned and opened fully and the water allowed to run to waste for two to three minutes or a sufficient time to permit clearing of the service lines. The flow from the tap should then be restricted to permit filling the bottle without splashing. Leaking taps which permit water to flow over the outside must be avoided as sampling points.

In collecting samples directly from a river, stream, lake, reservoir, spring, or shallow well, the aim must be to obtain a sample that is representative of the water which will be taken for purposes of supply to consumers. It is therefore undesirable to take samples too near the bank or too far from the point of draw-off, or at a depth above or below the point of draw-off. In a stream, areas of relative stagnation should be avoided.

Samples from a river, stream, lake, or reservoir can often be taken by holding the bottle near its base in the hand and plunging it, neck downwards, below the surface. The bottle should then be turned until the neck points slightly upwards, the mouth being directed towards the current. If no current exists—as in a reservoir—a current should be artificially created by pushing the bottle horizontally forward in a direction away from the hand. If it is not possible to collect samples in this way, a weight may be attached to the base of the bottle, which can then be lowered into the water. In any case, damage to the bank must be guarded against; otherwise, fouling of the water may occur. Special apparatus which permits mechanical removal of the stopper of the bottle below the surface is required to collect samples from the depths of a lake or reservoir.

If the sample is to be taken from a well fitted with a hand-pump, water should be pumped to waste for about five minutes before the sample is collected. If the well is fitted with a mechanical pump, the sample should be collected from a tap on the discharge. If there is no pumping machinery, a sample can be collected directly from the well by means of a sterilized bottle fitted with a weight at the base; in this case, care should be taken to avoid contamination of the sample by any surface scum.

Data relative to samples

1. Name and address of person requesting the examination
2. Reasons for examination; routine sample or otherwise
3. Exact place from which sample was taken; if from a house tap, whether drawn through a cistern, or directly from the main

4. Whether source is a well, spring, stream or public supply

5. What method of purification or disinfection is used, if any, and at what point it is applied; dose (in mg/l) of disinfecting agent employed

6. If from a well:
(a) depth of well, and of water surface from ground level
(b) whether covered or uncovered; nature, material and construction of the cover
(c) whether newly constructed or with any recent alterations which might affect the condition of the water
(d) construction:

    (i) bricks set dry or in cement;
    (ii) cement- or cylinder-lined, and whether puddled outside the lining;
    (iii) depth of lining;
    (iv) whether bricked above ground surface; if so, height of coping;
    (v) presence and extent of apron;
    (vi) method of pumping or other means of raising water

(e) proximity of drains, cesspools, or other possible sources of pollution, and distance from source
(f) any discoloration of the sides of the well, or other visible indication of pollution
(g) nature of subsoil and water-bearing stratum
(h) when available, a section or drawing of the well and its general surroundings is desirable.

7. If from a spring:
(a) stratum from which it issues
(b) whether sample was taken direct from spring or from a collecting chamber; if the latter, type of construction of chamber

8. If from a river or stream:
(a) depth below surface at which sample was taken
(b) whether sample was taken from the middle or side
(c) whether the level of water is above or below the average
(d) conditions of weather at time of sampling, and particulars of any recent rainfall or flood conditions
(e) observations with reference to any possible sources of pollution in the vicinity, and approximate distance from sampling point

9. Whether water becomes affected in appearance, odour or taste after heavy rain

10. Temperature of water at time of sampling

11. Date and time when sample was taken and dispatched

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Preservation and storage of samples

The bacteriological examination of samples of water should be initiated immediately after collection. However, such a requirement is seldom practical; and more realistic ones must be established.

It is therefore recommended that, with samples intended for bacteriological examination, the technical procedures should be started as soon as possible, preferably one hour after collection; the time elapsing between collection and examination should in no case exceed 24 hours. During the period elapsing between collection and examination, the temperature of the sample should be maintained as closely as possible to that of the source of the sample at the time of sampling. The time and temperature of storage of all samples should be recorded and should be considered in the interpretation of the laboratory results.

When local conditions necessitate delays in excess of 24 hours, consideration should be given to providing for a field examination of samples, by making use, for example, of the microfilter technique or of temporary laboratory facilities at the site.

Size of samples

The volume of a sample of water should be sufficient for carrying out all the tests required, and preferably not less than 100 ml for samples intended for bacteriological examination.

Frequency of sampling

The frequency of bacteriological examinations for the control of the sanitary quality of a supply, and the location of the sampling points at pumping stations, treatment points, reservoirs and booster pumping stations, as well as in the distribution system, should be such as to enable proper supervision of the bacteriological quality of the water supply to be maintained. Inspection of the entire water-supply system from source to consumers' premises is of the utmost importance, and the authority responsible for operation and safety of the water supply should have the services of an expert adviser in deciding on the sampling points and the frequency with which samples from each point should be collected.

For small towns and villages the population of which is less than 20 000 inhabitants, the maximum interval between successive samplings should be one month.

Physical and Chemical Examinations

Collection, transport, and storage of samples

For general chemical examination, a sample of at least 2 litres is required. It should be collected in a chemically clean bottle made of good quality (neutral) glass, practically colourless, and fitted with a ground-glass stopper.

The bottle should be rinsed out at least three times with the water that is to be sampled before the bottle is filled. Polyethylene bottles should be substituted for glass bottles for the special purpose of measurement of radioactivity in a sample.

In collecting samples for chemical analysis, the general recommendations given for the collection of samples for bacteriological examination (see above) should be followed.

In the collection of samples from mineralized sources, the bottle should be completely filled and the stopper securely fastened.

Samples should be transported to the laboratory with as little delay as possible and should be kept cool during transport. Chemical analysis should be started as soon as practicable after the collection of the sample, and in any case should not be delayed for more than 72 hours.

Data relative to samples

A record should be made of every sample collected, and every bottle should be identified, preferably by attaching an appropriate tag or label. The record should include sufficient information to provide positive identification of the sample at some later date; e.g., name of the sample collector; date, hour, and exact location of sampling; water temperature; details of any treatment of the water; and any data which may be needed for future reference, such as weather conditions, water level, or stream-flow. Sampling points should be fixed by detailed description, by maps, or with the aid of stakes, buoys, or landmarks, in such a manner as to permit their identification by other persons.

Frequency of sampling

Collection of samples of both raw and treated water for examination for toxic substances should be carried out at least once every three months, and more frequently when sub-tolerance levels of toxic substances are known to be generally present in the source of supply, or where such potential pollution exists—as, for example, in an area where industries may be discharging toxic wastes into sources of a water-supply.

Samples for general systematic chemical examination should be collected at least once every three months in supplies serving more than 50 000 inhabitants, and at least twice a year in supplies serving up to 50 000 inhabitants. More frequent sampling for chemical examinations may be required for the control of water-treatment processes.

Sampling of new sources of supply. Frequent examinations both for toxic substances and for general chemical analysis will be required for new or proposed sources, depending on local circumstances, which may necessitate establishing special periods for sampling.

CONSTRUCTION OF HAND-DUG WELLS *

The sinking of a new well is here described in detail, starting with the arrival of the well crew (headman, second sinker, and four labourers) on the site with their equipment. This method is used extensively in Northern Nigeria, but may need to be modified for application elsewhere.

Preliminary Steps

First, the site is cleared and a working space of about a 50-ft (15-m) radius is freed of all bush and is roughly levelled; the headframe is then erected. The next task is to construct a shelter to house tools, cement, etc. The nature of this building will vary according to the season, location, and local materials available, and whether there is danger from fire, thieves, or animals; but, generally, it consists of a grass-walled hut with a thatched roof. A locally engaged watchman is usually necessary to protect materials and equipment.

A mixing slab is now constructed. This is about 6 ft 6 in. (2 m) square, with the nearest side 6 ft (1.8 m) from the front legs of the headframe (i.e., the legs opposite those holding the winch). The slab is made by levelling off the area, spreading gravel, tamping to a finished thickness of about 2 in. (5 cm), and covering the surface with a 4 : 1 sand · cement mix trowelled to a smooth finish.

One set of lining shutters, 4×2 ft (1.22×0.61 m), is assembled and centred on the ground below the headframe in the exact position of the well. Having marked the circle on the ground, a hole 18 in. (45 cm) deep and 4 ft (1.22 m) in diameter is excavated and the lining shutter set in this hole so that the top edge is exactly level and 6 in. (15 cm) above the ground. The outside earth is well rammed round this shutter, which will remain in place during the sinking of the first section of well and until this first section is concreted. The purpose of leaving the shutter in place is (a) to prevent the top edge of the well from crumbling, particularly when knocked by buckets, etc.; (b) to make a raised curb or mound round the well top to reduce the

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Fig. 81. PLUMBING RODS

Plumbing rods
loosely riveted

Plumbing peg
with V notch

Plumbing peg
hole drilled

G.L.

Lining shutter
4'0"Ø

2' 0"

Concrete

Trimming rods
loosely riveted

3/4" Ø
hole

5/8"

1" Ø Plumbing peg

Plumbing rods
loosely riveted

2' 0"

TOP PLUMBING RODS

3/4" hole drilled

3/4" hole drilled

5/8" Ø Plumbing pegs

5/8"

2' 0"

6' 4"

ALTERNATIVE METHOD
FOR PLUMBING RODS

WHO 9161
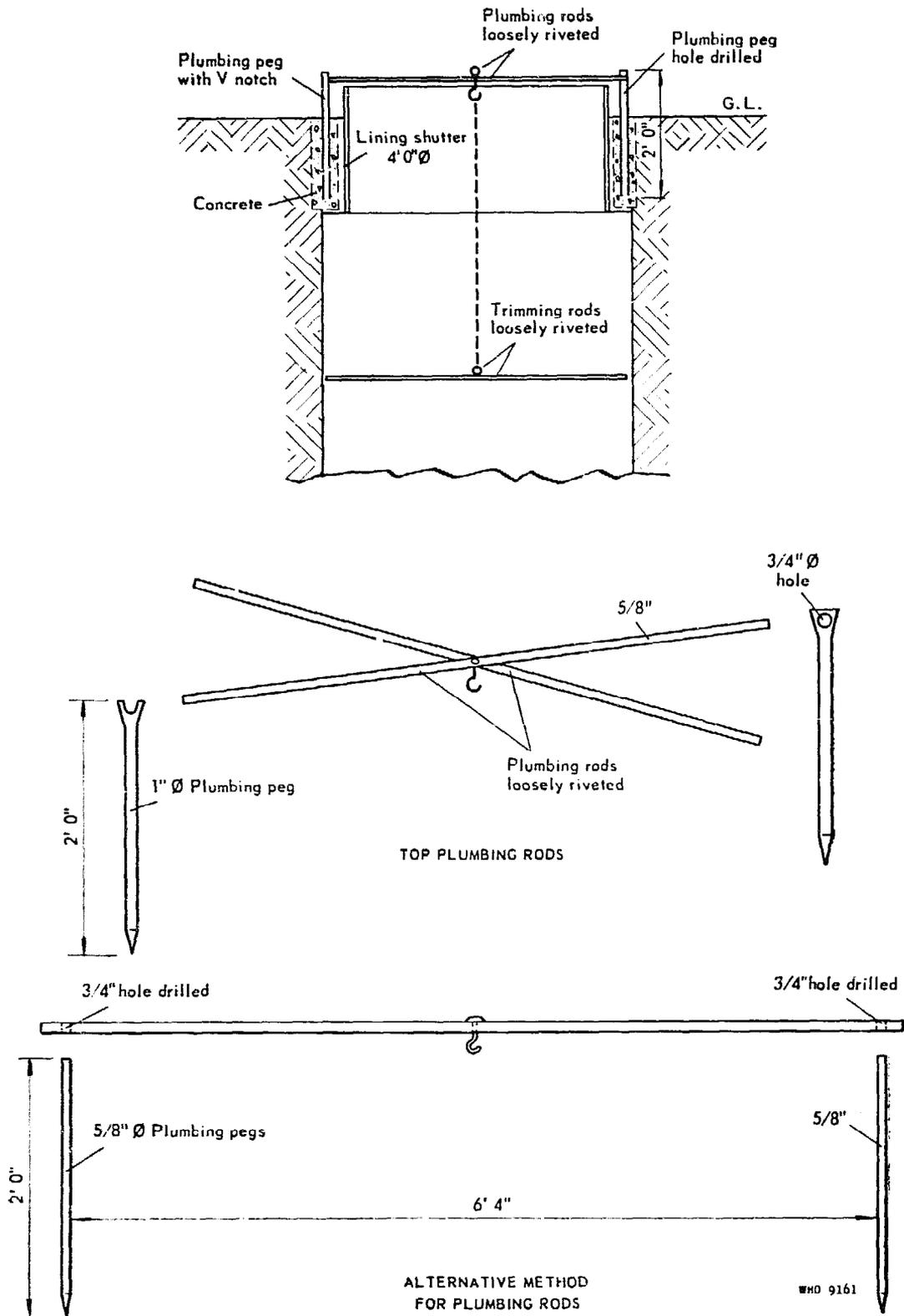
risk of stones, tools, or other heavy objects being accidentally knocked into the well mouth to the danger of sinkers working below; and (c) to assist in keeping the well plumb, and to form a fixed level for taking measurements.

The next stage is to fix into position the four plumbing pegs. These are made from 1-in.- (25-mm-) diameter rod, each 2 ft (60 cm) long (see Fig. 81). Two have $1/_2$-in.- (12-mm-) diameter holes drilled through the thickness of the rod 1 in. (25 mm) below the top. The other two each have a V-shaped notch cut in the top.

Part of the equipment of the well crew consists of three sets of plumbing rods. Each set consists of two $5/_8$-in.- (16-mm-) diameter rods riveted loosely together at the centre so that they may fold together for transport and storage and open into a cross for use. These sets are $4^3/_4$ ft (1.45 m). $4^1/_2$ ft (1.37 m), and 4 ft (1.22 m) long, respectively, and are referred to as " top plumbing rods " ($4^3/_4$ ft), " long trimming rods " ($4^1/_2$ ft), and " short trimming rods " (4 ft). To set the plumbing pegs, the top plumbing rods are used. They are opened into a 90° cross, and one end of each rod is put through the hole in each of two plumbing pegs; the other two ends are laid in the V-shaped notches in the remaining plumbing pegs. These pegs are then set upright in concrete at equally spaced intervals around the lining shutter with the holes and notches immediately above the rim of the shutter. If properly set, the point where the plumbing rods are riveted together will be exactly in the centre of the well; they can be dismantled and reassembled at any time, and the rivet will always remain central. As sinking proceeds, the plumb of the well is constantly checked by assembling the top plumbing rods in the holes and nothces of the pegs, tying a line to the rivet, and lowering the long trimming rods, to the centre of which the other end of the line has been fastened. If the well is truly vertical and has been trimmed to shape and size (4 ft, or 122 cm, in diameter for the well plus 3 in., or 7.5 cm, all round for the thickness of concrete = $4^1/_2$ ft, or 1.37 m), these long trimming rods will just revolve freely on the end of the line.

The short trimming rods are used only in hard material such as rock, where no concrete lining is necessary and only the bare diameter of the well is to be excavated, and for setting the lining shutters as described later.

There is an alternative, and somewhat simpler, method of plumbing which uses a single top plumbing rod $6^1/_2$ ft (2 m) long, 1 in. (25 mm) in diameter. At 1 in. (25 mm) from either end, a $3/_4$-in. (19-mm) hole is drilled and a small deep hook is riveted at the exact centre of the rod with the shank of the hook parallel to the axis of the holes.

Two $5/_8$-in.- (16-mm-) diameter plumbing pegs only are used, set in concrete as before, but $6^1/_3$ ft (1.93 m) apart, corresponding to the two holes in the plumbing rod. These are fixed and concreted before setting the first set of lining shutters described earlier, and these shutters must be accurately positioned so that the hook in the plumbing rod is exactly central.

The plumbing rod can then be lifted off the pegs and returned when plumbing operations are required : the trimming rods are the same and are used in a similar manner with this method.

Excavation

Sinking can commence as soon as the plumbing pegs have been fixed• Tools used are miners' picks, bars, and short-handled shovels. Two men work inside the well, and each should wear a miner's helmet. Where sinking is in dry clay, a bucket of water into which the shovel can be dipped frequently will make excavation a great deal easier. Loosened earth is brought to the surface in a kibble (hoisting-bucket) hoisted by two men on the winch—the $^1/_2$-in.- (12-mm-) diameter wire-sinking rope being used for this purpose. The kibble is so designed that it cannot tip or otherwise spill its contents on the men working below, even if it accidentally fouls a projection while it is being raised.

During the sinking process the two men not engaged on excavation and winching should be occupied in the manufacture of caisson rings and tongued blocks. The construction of the caisson rings will be described later, but both they and the blocks should be started as early as possible so that the maximum time can be allowed for curing and hardening. They are cast on the mixing slab and, when made, should be moved into the shade, covered with grass, and kept wet for at least a week after manufacture.

The tongued blocks are made of concrete and are cast in wooden moulds. The over-all size of each block is $8 \times 4 \times 4$ in. $(20 \times 10 \times 10$ cm), and the dimensions of the recesses are clearly shown in Fig. 82. Their use will be explained in due course.

Provided that the ground is reasonably hard and not too wet it should be possible to take the first " lift " to a depth of 15 ft (4.5 m) without any danger of collapse. In normal ground the thickness of concrete will be 3 in. (7.5 cm); and the long trimming rods should just, and only just, turn in the trimmed hole. The more accurate the trimming is the better, as a variation of 1 in. (2.5 cm) over size makes a difference of $33^1/_3\%$ in the amount of cement used. In bad ground, such as running sand, heaving or squeezing clays and shales, etc., it may be necessary to increase the thickness of the concrete lining to 4 in. (10 cm), 5 in. (12.5 cm.), or, in extreme cases, 6 in. (15 cm); but this should be decided by a responsible officer and should not be left to the discretion of a headman. In a new area the inspector or other officer in charge will keep an extra close watch on the first well sunk so that he may judge the lining thickness at different levels; after a few wells have been sunk in the vicinity, he will normally know the types of ground likely to be encountered and can instruct the headman accordingly. If a number of wells with thicker linings are to be built, special trimming

Fig. 82. LOCALLY MADE EQUIPMENT
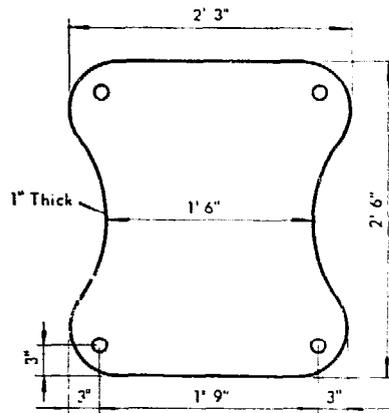
BOSUN'S CHAIR
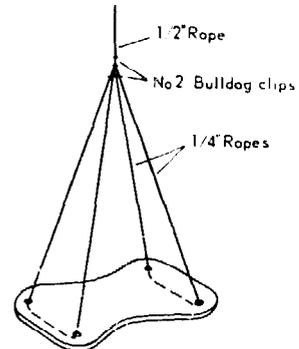
BOSUN'S CHAIR
SKETCH SHOWING METHOD
OF SUSPENDING
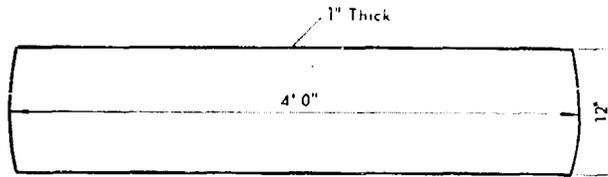
CONCRETING SCAFFOLD BOARD
(To wedge across ribs of lining shutter)
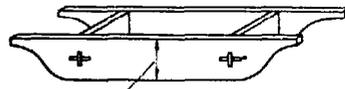
6"High for sand
12"High for gravel

2' 6"X 2' 6" BOTTOMLESS BOX
FOR GAUGING CONCRETING AGGREGATE

CONCRETING SCOOP

SUPPORTING PINS
3/8" M.S.R.
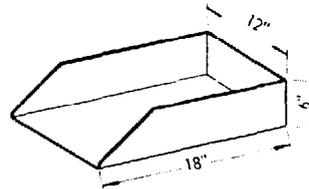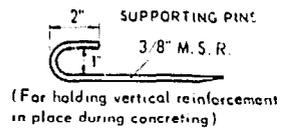
(For holding vertical reinforcement
in place during concreting)
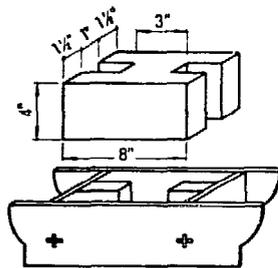
TONGUED BLOCK AND MOULD

3/4"M.S.R.
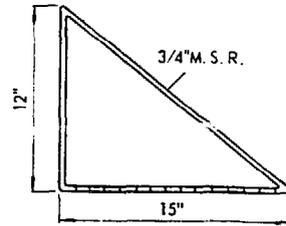
CURB UNDERCUT GAUGE

LOCALLY MADE EQUIPMENT
Not to scale

WHO 9160

rods to the new over-all diameter should be supplied; but, if the amount of over-size sinking is small, wooden distance pieces are commonly used with the ordinary long trimming rods.

Lining

The first lift is now ready for lining. It has been sunk 15 ft (4.5 m) deep and trimmed exactly to $4^1/_2$-ft (1.37-m) diameter; the bottom has been levelled. The mouth of the well is still protected with one set of lining shutters, and these must be left in place during concreting operations.

One set of lining shutters 2 ft (61 cm) high is now lowered to the bottom of the excavation, bolted together, levelled, and accurately centred with the short trimming rods. It is most important that this first set shall be exactly positioned as the whole of the lift will be thrown out if the bottom set is out of level or centre. As soon as it is in position, the space between the shutter and the excavation is loosely filled with earth. The $^3/_8$-in.- (10-mm-) diameter mild steel rods which are to be used as vertical reinforcement have their lower ends pushed into this loose earth. The remainder of their length is supported by pins (made from short ends of reinforcement) driven into the sides of the well so that the rods are held in the position in which they will be finally concreted. If 20-ft (6-m) lengths of reinforcing rods are used, then they will project 5 ft (1.5 m) above ground level; and these projections should be carefully bent back and pinned to the ground, as they will be required later.

The number of rods used in the vertical reinforcement will vary according to the nature of the ground. Occasionally no rods are necessary. (This applies only when sinking takes place in fissured rock or similar self-supporting ground where no strength is required from the lining, but only a waterproof barrier to keep out contaminated surface-water.) As many as 19 rods may be needed in bad ground, but under normal conditions seven is a usual number.

These seven rods, then, are anchored at their bottom ends and supported throughout their length at a distance of $1^1/_2$ in. (4 cm) from the face of the excavation. A second set of shutters is now added above the first, centred with the trimming rods, and bolted in place. The space behind is filled with concrete. These shutters, and all others subsequently used for concreting, should have their outside faces well oiled with old engine oil to prevent the concrete from sticking to the metal, and to give a clean face to the well wall when the shutters are finally removed.

This concrete is mixed by hand on the mixing slab to the proportions of $5 : 2^1/_2 : 1$ of gravel, sand, and cement. As a simple means of gauging, two bottomless boxes $2^1/_2 \times 2^1/_2 \times ^1/_2$ ft ($75 \times 75 \times 15$ cm) are used, one 1 ft (30 cm) deep to measure the gravel, the other 6 in. (15 cm) deep to measure sand. When mixed with 1 hundredweight (50.8 kg) of cement, these quan-

tities give the correct proportions and, in quantity, a little more than is required to fill behind one 2-ft (61-cm) shutter of 3-in. (7.5-cm) thick lining. The gravel or other aggregate should pass a $^3/_4$-in. (19-mm) mesh sieve but should be retained on a $^1/_4$-in. (6-mm) mesh; the sand should be good, sharp, river sand. It is essential that both sand and gravel be clean, free from soil and clay, and well mixed with the cement. Two mixings dry and two further mixings after the water has been added should be the minimum to ensure a strong concrete.

Water is frequently a problem on the first lift. In dry areas there will be no water seeping into the well until a considerable depth is reached, when the seepage can be collected first thing each morning before work in the well has muddied up what has drained in overnight. However, until such a depth has been reached, water will probably have to be transported to the site; it is usually carried in old petrol drums, either rolled by hand or brought in on a trailer or lorry. Too much care cannot be taken to ensure that the water is as clean as can be obtained : it should not contain mud, clay, oil, or any other impurity which may weaken the concrete or slow its setting; and extra trouble or expense in bringing good water to the site is usually well worth while. The quantity of water added to the mix will depend on the dryness of the sand and aggregate, but a good rule-of-thumb method for seeing whether the water content of the freshly mixed concrete is correct is to take a handful of the wet mixture and squeeze it hard : it should just be possible, but only just, to squeeze out two or three drops of liquid from the handful.

The concrete is lowered in the concreting bucket on the $^1/_4$-in.- (6-mm-) diameter wire connecting rope over the auxiliary headsheave. The winch is not used for this lowering, which is done by hand-pulling on the rope; and care must be taken that the bucket, which has a lip for pouring the concrete, does not foul the side or any projection which might tip the contents onto the men working below.

It is usual for a short piece of wood to be tied to the upper end of the $^1/_4$-in. (6-mm) connecting rope to act as a handle when lowering. This, unless carefully done, can be a cause of accidents. The man or men doing the lowering normally hold the wooden handle and walk slowly to or from the well head so that when the bucket is at the surface the handle is at a distance from the sheave equal to the depth of the well. The full bucket is then swung over the well mouth and the strain is taken on the handle. Should this piece of wood slip out of the loop at the end of the rope, or break, the full bucket will obviously fall onto the men working below. For this reason it is most important that a strong, round stick about 2 ft (60 cm) long should be chosen for the handle, and the rope should be fastened tightly round its centre in a clove hitch. The loose end should then be fastened to the main rope with a bulldog clip. The knot and clip should be inspected regularly to see that they have not worked loose.

On reaching the bottom, the concrete is poured behind the shutter carefully and tamped well round the rods with a short piece of reinforcement. The tamping is important to prevent voids, and care must be taken not to disturb the position of the rods, which should be in the centre of the lining thickness—i.e., $1^1/_2$ in. (4 cm) from the face of the lining. When the space behind the shutter is full, the concrete should be left rough so that a good bond is made with the next batch to be poured above. Whenever a break in the work occurs, either overnight or during a meal interval, the surface of the concrete should be cleaned and well wetted before the new mix is poured on. The whole of the concrete mixed should be used immediately; and if, for any unavoidable reason, work stops for more than 20 minutes before all the mix is used, it should on no account be placed in the well or remixed : it must be discarded and a new batch mixed.

When the pouring behind the second shutter (the first being earth-filled) has been completed, the first curb is made. This is done by cutting a groove in the earth side of the well immediately above the top of the second shutter. This groove penetrates the side 1 ft (30 cm) in depth (horizontally) all round, and the vertical width of this groove should be 8 in. (20 cm) at the well face, tapering to nothing at 1-ft (30-cm) depth. Seven pins (when seven reinforcing rods are used), each 20 in. (50 cm) long, are driven into this slit, the hooked ends holding the vertical rods in place. One horizontal rod ($^3/_8$-in., or 10-mm, diameter) is taken round the well and fastened with binding wire to each pin and vertical rod. Concrete is then hand-filled into the curb all round, the third set of shutters is bolted into place, and concrete is poured behind. With the fixing of the third shutter, the top will be too high for a man to work from the well bottom. Pouring and tamping will therefore be done from a " bosun's chair " suspended from the $^1/_2$-in. (12-mm) rope on the winch.

Two more sets of shutters are fixed in turn and concreted. The top of the lining is now 5 ft (1.5 m) below ground level, and the concrete should be left overnight before the next step. This consists in forming a collar round the top 5 ft (1.5 m) in the well to support the well top or pump unit, and to protect the well during construction at its weakest part—i.e., where it passes through the top soil. The shutters are left below in position to support the concrete previously poured (these shutters should not be removed for at least a week), and the side of the well is excavated until it is 5 ft (1.5 m) in diameter. At this stage the temporary shutter originally put in to protect the well-mouth is removed, but care should be taken not to disturb the plumbing pegs in their concrete bases. When the trimming is finished, three additional shutters are added and concreted one at a time. The thickness of the concrete lining will now be 6 in. (15 cm). When the concrete around the plumbing pegs is reached, the new lining is carefully poured around so that these pegs are incorporated into the well-collar.

Before concreting the topmost lining, the ends of the vertical rods, which were previously pegged to the ground, are unpegged and bent round the well at about 2 in. (5 cm) above ground level. The concrete is poured round these and finished 6 in. (15 cm) above ground level (the top lining will be projecting 1 ft, or 30 cm, from the ground) to form a dwarf wall around the mouth of the well. This not only protects the well during construction in the same way as did the temporary lining left in earlier, but also acts as a " key " for the well top when it is constructed later. In the rainy season it has the additional duty of keeping out surface water which might run into the well if it were finished flush with the ground.

The first lift is now complete, and consists of 13 ft (4 m) of concrete lining supported on a curb, 6 in. (15 cm) of walling above ground, and an extra 2 ft (61 cm) of unlined excavation. The second lift is now excavated while the lining to the top lift remains in position, except that the bottom section (which has only earth filling behind) is removed. The second lift is excavated to a depth of 14 ft 5 in. (4.39 m) below the concrete lining of the first lift; one set of shutters is assembled, plumbed, and earth-filled at that depth; and seven more vertical rods (which have been cut to 14-ft, or 4.27-m, lengths) are pushed into the earth behind the lining as before. The lower ends of the reinforcing rods to the top lift will be projecting 2 ft (61 cm) below the concrete (being that portion of the rods which was in the earth behind the first shutters), and the tops of the rods of the second lift are bound to these projecting ends with binding wire; but, before being bound together, the tops of the lower rods and the lower ends of the upper rods are each bent into a hook about 3 in. (7.5 cm) in diameter to enable them to grip the concrete. The upper rods will almost certainly be muddy where they were stuck into the earth behind the first shutters; they should be cleaned with a wire brush before being surrounded with concrete. The procedure for concreting and construction of the curb to the second lift is exactly the same as that for the first lift, with the exception that the top of the concrete will finish 5 in. (12 cm)·below the bottom of the completed lift. To pour behind the top shutter of the second and subsequent lifts, a funnel or chute is necessary; this usually consists of a piece of beaten-out " pan " suitably shaped. Without such a chute a great deal of concrete will be wasted in an attempt to pour into a 5-in. (12-cm) gap with the spout of the bucket.

This is where the tongued bricks are used : being 4 in. (10 cm) in thickness, they will go easily into the 5-in. (12 cm) gap, and the recesses in the ends allow them to be manoeuvred into position around the reinforcing rods. The bricks may need cutting to fill the gap completely round the well; and, when all have been placed in position, they are fastened into place with cement mortar and pointed with a pointing trowel to leave a smooth surface. It is usually found preferable to leave the pointing until after the linings have been removed, as this allows a better finish to be made;

but, if there is much water in the ground outside, it will have to be done immediately to prevent earth being washed through the gaps in the bricks.

The routine is now continued until the aquifer is reached. Each successive lift has its own curb and is therefore independently supported. The lining shutters from the first lift are taken out when required for the third, the second for the fourth, and so on. When the aquifer is neared, or when unstable ground is encountered, lifts should be shorter. In addition, the judicious use of 1-ft (30-cm) high linings enables any multiple of a foot to be excavated at a time; but there should always be a 5-in. (12-cm) gap between successive lifts to enable the tongued bricks to be used for continuity.

Caissoning

When the aquifer is reached, and sinking and lining are no longer practicable owing to the influx of water, an extra-deep curb is constructed at the bottom of the concrete and the lower ends of the rods are bent into the concrete of this curb. Further sinking is then carried out with caisson rings (see Fig. 83).

These rings will have been cast on the surface, cured, and will by now be ready for handling. Each ring is cast in a mould with an internal diameter of 3 ft 1 in. (94 cm) and an outside diameter of 3 ft 10 in. (117 cm), the height of the cylinder being 2 ft (61 cm). Four equally-spaced vertical holes are cast into these cylinders by inserting pieces of well-oiled pipe or rod, $3/4$ in. (19 mm) in external diameter, during the pouring of the concrete. Midway between these holes four bolts are set into the cylinder wall. These bolts consist of $5/8$-in. (16-mm) rods 4 ft in length, with the upper end, which projects 2 ft (61 cm) from the caisson, threaded to take a washer and nut. About 1 in. (25 mm) from the lower end, a hole $1/4$ in. (6 mm) in diameter is drilled through each rod and a short piece of $3/16$-in. (4.8-mm) wire, or, more commonly, a nail, is inserted to act as a key to prevent the rod from being pulled out of the concrete.

Both the pieces of oiled pipe and the bolts are held in position in the mould by means of top and bottom templates during pouring, and the pipes are carefully pulled from the " green " concrete not less than 12 hours and not more than 24 hours after casting. The outside mould may be struck at the same time, but the ring must not be moved for at least three days, during which time it should be covered with grass or leaves and kept thoroughly wet. At the end of three days, the ring may be rolled carefully into the shade where the curing process (shade and water) must continue for at least a week. With porous concrete—the precautions for which are described separately—this period should be doubled if possible. Porous concrete will normally be used if the aquifer is of coarse sand, gravel, or decomposed rock. Plain concrete rings are preferable if the sand is very

Fig. 83.   CAISSONS AND LINING SHUTTERS

CAISSON MOULD

CAISSON RING

CAISSON MOULD

CAISSON MOULD TEMPLATE

SECTION OF LINING SHUTTER

LINING SHUTTER
(Set of 3 make one 4' Ø cylinder)

LINING SHUTTERS

WHO 9162
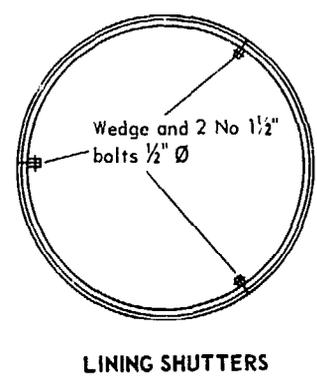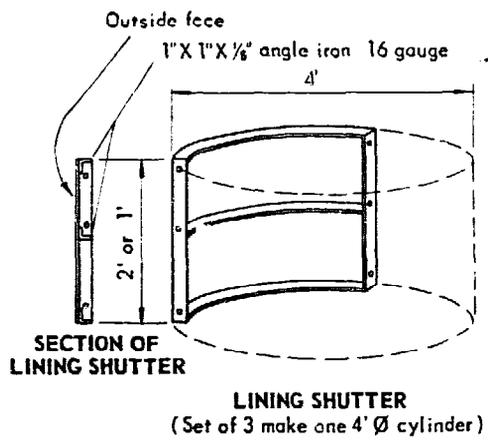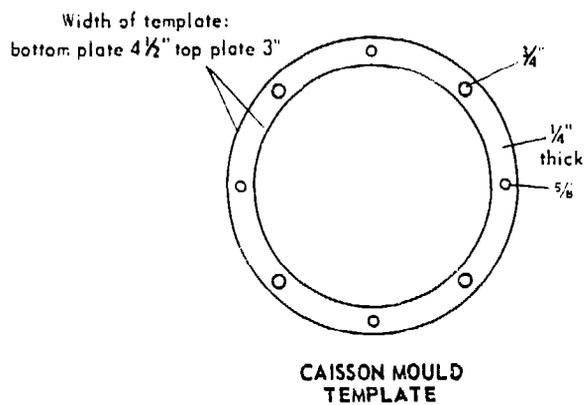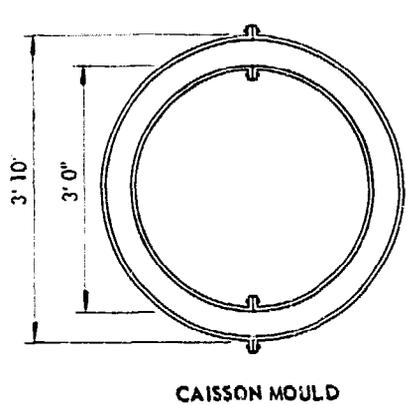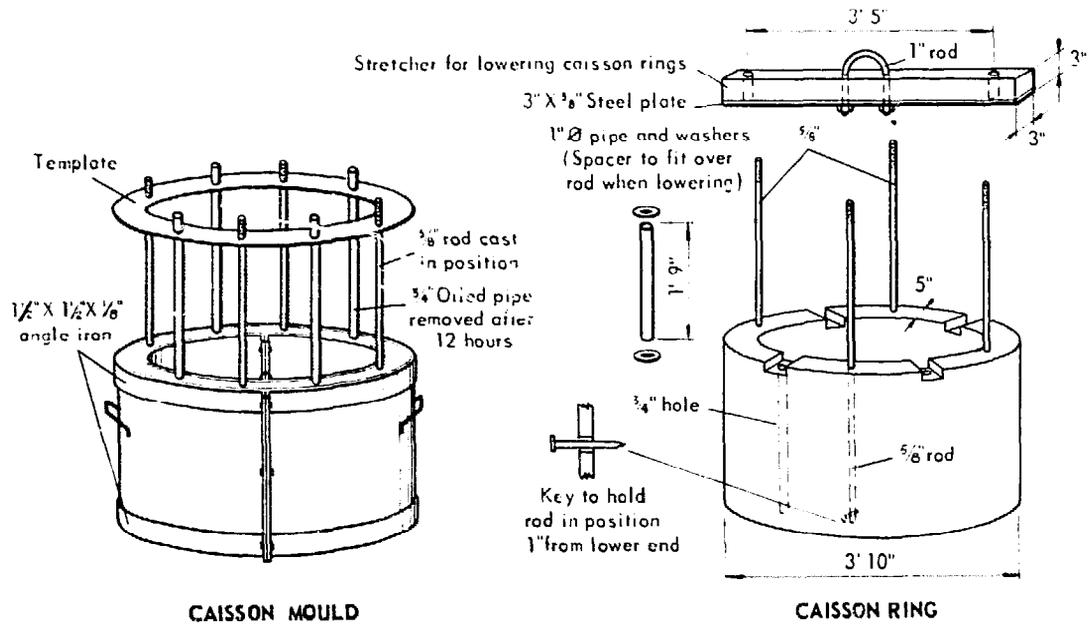
fine, and also where it is desired to shut off one aquifer and draw from a lower one.

During the casting of the caisson rings, slips of wood are inserted at the upper end of the four holes. When the rings are removed from the moulds these wooden blocks are also removed and space is thus left for the nuts to be screwed on to the bolts below the top surface of the concrete.

To commence caissoning, the first ring is rolled to the side of the well and stood vertically with the four bolts projecting upwards. To lower the ring down the well, a " stretcher " is used. This stretcher consists of a piece of timber 3 ft 10 in. (1.16 m) long with a $^3/_4$-in. (19-mm) hole 2 in. (5 cm) from each end. In the centre is fixed a ring or an eye bolt. The stretcher fastens on to two opposite caisson bolts, which are passed upwards through the $^3/_4$-in. (19-mm) holes. Two spacers, made of 1-in.- (2.5-cm) diameter pipe with washers at either end, are placed over the bolts so that, when the nuts are screwed into place, the stretcher is held tight to the upper surface of the caisson ring. When the tumbler hook on the $^1/_2$-in. (12-mm) wire rope from the winch is passed through the centre ring of the stretcher, the caisson ring can be raised and lowered absolutely vertically and manœuvred into any desired position. Stretchers can be made of metal rod welded into shape, but care must be taken that such stretchers are strong enough not to bend when taking the weight of the ring; otherwise, the caisson bolts will become distorted and will not fit into the ring above accurately.

Before lowering the ring, the headman should descend the well and probe the bottom with a sharpened piece of $^5/_8$-in.- (16-mm-) diameter rod about 5 ft (1.5 m) long. It is most important to know how soft the formation is below the caissons because the topmost ring must not on any account be allowed to leave the lining. A sufficient number of rings must always be fixed together to allow for a sudden sinking if very soft ground is encountered in the aquifer. Occasionally a hard band of clay in the aquifer will hold up progress; and, on passing through this, the whole caisson will suddenly slip downwards sometimes 5 ft (1.5 m) or more. Provided that four or more rings remain inside the lining, this will not matter, because the lining will act as a guide, keeping the caisson vertical.

The first ring is now lowered to the bottom of the well. The headman usually descends the well sitting on the stretcher. There is some doubt as to whether it is safer for him to descend with the ring in this manner or to await the rig at the bottom of the well, but the first method is considered to be the better because he can watch the rope clips as he goes down and, should they slip under the weight, he can grasp the rope above the clips and save himself. If the clips were to slip when he was below, there would be considerable danger from the falling ring even though he would be protected inside the lower caisson. When in place, the top edge of the ring is coated with cement mortar about $^1/_2$-in. (12-mm) thick; and the second ring is lowered. As ring number two approaches the bottom one, it is

turned into position by the headman so that the projecting bolts in the lower ring penetrate the holes in the upper. When in place, nuts are screwed home and preparation is made for the third ring. When four or five rings are firmly jointed together, sinking continues by hand digging inside the caisson, water and sand being removed by the kibble (hoisting-bucket). As the caisson goes down, further rings are added until water is entering at such a rate that it is no longer possible to keep its depth down by bailing with the kibble. That is the limit to which the well can be sunk.

If the water table is low due to the season of the year, the well may be finished off by concreting the bottom (if the caissons are of porous concrete) or putting in a gravel filter if it is desired that water should enter through the bottom. However, if the water table is expected to drop later in the dry season, then four or five caisson rings should be left projecting upwards in the lining so that a deepening crew can return at the season of low water table and sink the caisson lower without having to cast new rings. Whether the well is being left temporarily or permanently, the circular space between the lining and caisson must on no account be filled with cement mortar or stone. If for any reason (such as the entry of fine sand or contaminated water) it is desired to seal this space, it should be plugged with clay or with bitumen and sand, either of which will allow for settling of the caisson later without danger of breaking away the lining.

Running sand is sand not only waterlogged but actually moving under the influence of flowing water. This condition can be tackled only by caissoning. However, waterlogged sand—frequently miscalled " running " sand—can be successfully lined provided that very short lifts are used. When there is insufficient strength in the well wall to construct a proper curb, then a small curb a few inches in depth should be made at the top of each shutter and a horizontal rod should be put in each.

Dry " sugar " sand which slides under its own weight can usually be dealt with by putting in lining shutters, sinking these into position one by one as though they were caisson rings, and pouring water behind these shutters until the wall is saturated. Again, very short lifts—one foot (30 cm) high if necessary—should be used; and, if there is any doubt as to the ability of the soaked wall to stand under its own weight, then caissoning should be resorted to, as this type of ground can be very dangerous if left unsupported. When a lining is being constructed in this very dry sand, curbs are not necessary provided that the concrete used is very wet and contains a higher proportion of cement. This cement penetrates the dry material and gives a very high skin friction which is better than curbs. Reinforcement should be cut to short lengths about $1\frac{1}{2}$ ft (45 cm) longer than the shuttering used, and the lower ends of these reinforcing rods should be bent into the bottom of the well and pegged down, to be straightened out and bonded to the lift below when that is excavated. Again,

with this dry sand, the tongued bricks should be pushed into place between lifts and not pointed until the whole of the dry stratum has been lined. It will usually be found necessary before pointing to pour more water through the bricks and have the ground behind thoroughly wetted before finishing off with cement mortar.

Ventilation

In wells more than 200 ft (61 m) deep, and in certain formations at shallower depths, artificial ventilation becomes necessary. Crude temporary methods of increasing the air supply include the sprinkling of water or dry sand down one side of the well, to set up an air current, and the rapid raising and lowering of a kibble or large bundle of grass on the end of a rope. Bad atmosphere can even be improved by pumping up the inner tubes of lorry tires on the surface, lowering to the bottom and releasing the air slowly. One man fully engaged in pumping a succession of three tires constantly interchanged can just about keep air enough for one man to work at the well bottom. However, for sustained work in a bad atmosphere, a motor-driven fan is used, mounted at ground level near to the well top with an air pipe of light metal or flexible rubberized material to conduct the air down the shaft. It is neither necessary nor desirable to carry the pipe down to the working space, as a cold draught can be dangerous to the health of men perspiring from hard work. The pipe is usually finished off with a bend about 20 ft (6 m) above the work to avoid a direct stream of air on the sinkers.

Other Points

Mechanical pumps should preferably not be used to keep the water down during sinking, as withdrawing water rapidly will almost always cause caving behind the lining or caissons, with danger of collapse or sideways movement. The only exception where pumps can be used is in material such as sandstone or fissured limestone in which the inflowing water will not move the material of the aquifer.

The date of casting of each caisson ring should be scratched into the green concrete so that a check can be kept of its age. This will assist in ensuring proper curing and the use of the rings in order of age. Before starting to lower the first caisson ring, the bulldog clips fastening the rope to the tumbler hook should be checked. Frequently these loosen with the expansion and contraction of the metal; and the weight of the caisson ring, which is over 150 kg, can cause the rope to slip from the clips, with extremely dangerous results. At least two bulldog clips should always be used when lowering caissons, and the wire rope must be free from wear. Before

lowering, the headsheave, tumbler-hook, and brake should be inspected. There should never be fewer than two men on each handle, with the second headman on the brake; the headman is lowered with the ring.

A close watch should be kept on the tools used, particularly the mixing shovels. The constant sliding along the surface of the mixing slab soon sharpens the edges of these shovels to razor-keenness, and they tend to wear unevenly so that sharp projections occur. More accidents are attributable to men's ankles being cut by such projections than to any other cause. The remedy is to have the shovel blades cut off square with a cold chisel or by a blacksmith, and not to use shovels for mixing once they have worn too far to be so cut.

Shutters should be cleaned after every pouring of concrete. If the shutters are properly oiled before use, little concrete will adhere to their faces; any concrete that does adhere to them should be scraped and wire-brushed off. Hammers must never be used to clean shutters as they will ruin the faces. If a shutter is distorted in any way, it should not be used until it has been reshaped on a template.

When shutters are bolted together during lining operations, the vertical joints should always be in line one above the other. This helps to keep the well plumb.

Equipment and Tools

Well-sinking and concreting equipment

(1) Headframe : after trying various types of headframe, the one found to be of most use in Northern Nigeria is that known as type " G " (see Fig. 84). It is constructed with four legs of $2^1/_2 \times 2^1/_2 \times ^1/_4$ in. ($63 \times 63 \times 6$ mm) angle iron, crossed-braced with $1^1/_2 \times 1^1/_2 \times ^1/_4$ in. ($38 \times 38 \times 6$ mm) angle iron. It is 14 ft (4.27 m) high to the centre of the main headsheave and 12 ft (3.66 m) between the front and back legs; the front legs are 3 ft 9 in. (114 cm) apart, and the back legs 6 ft (183 cm) apart. To the front legs at a convenient height is fixed the winding gear, with a 3 : 1 ratio cast-iron gear, winding handles, band brake, and a single arrangement whereby the hoisting drum (which can carry about 500 ft (150 m) of $^1/_2$-in- (12-mm) diameter wire rope) can be freed from the gearing but not from the brake. An auxiliary headsheave for the concreting rope is fixed about 2 ft (60 cm) from the top of the back legs. The whole can be dismantled, and each piece is light enough to be carried by a man, so that it is transportable where there are no roads.

(2) Winding rope (350 ft, or 105 m), $^1/_2$ in. (12 mm) in diameter; ordinary lay steel wire, best flexible ungalvanized; tensile strength of material, 80/90 British tons per square in. (12.5-14 metic tons per cm^2);

Fig. 84. SINKING HEADFRAME (TYPE " G "), NORTH REGION, NIGERIA: GENERAL ARRANGEMENT
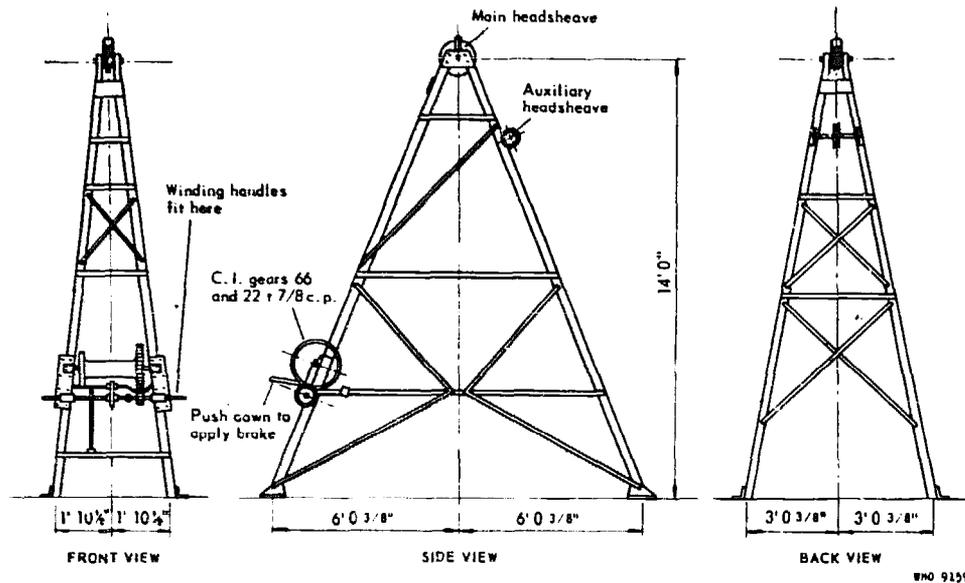
Scale: $1/4$ inch to 1 foot

acid grade; actual breaking strain, 7.2 British tons (7.3 metric tons); stranded 6×19 with fibre core.

(3) Concrete feed rope (350 ft, or 105 m) $1/4$ in. (6 mm) in diameter; best engineering guy rope, of similar specification to item 2.

(4) Plumbing rope (350 ft, or 105 m) $1/8$ in. (3 mm) in diameter; best engineering guy rope, of similar specification to item 2.

(5) Shuttering (six sets), each set consisting of three sections forming together a 4-ft- (1.22-m) diameter circle, 2 ft (61 cm) high.

(6) Shuttering (two sets), same as item 5 but 1 ft (30 cm) high.

(7) Wedges for shuttering (18 wedges) 2 ft (61 cm) long.

(8) Wedges for shuttering (six wedges) 1 ft (30 cm) long.

(9) Shuttering bolts (96 bolts) $1/2$-in. (12-mm) diameter, $1 1/2$ in. (40 mm) long, hexagon-headed, mild steel.

(10) Kibbles (hoisting-buckets), sinking (two kibbles), 2 cu. ft (56 l) capacity; made of thick steel, either welded or riveted; must be watertight; with the handle hinged at the top rim and not at the centre, so that it cannot tip up. The diameter at the centre should be greater than at the top and bottom to prevent any risk of catching on projections, and the handle should be twisted into a ring at the centre to prevent tipping sideways. These kibbles are used for the removal of excavated earth and also for

bailing water during construction.   They should weigh about 40 lb. (18 kg) each.

(11)   Concreting buckets (two buckets); height of body, $9^{1}/_{2}$ in. (24 cm); diameter at top, $11^{1}/_{2}$ in. (29 cm); diameter of bottom, 8 in. (20 cm); with a spout projecting 3 in. (75 mm) for pouring concrete behind shuttering, and with the centre of the handle twisted into a ring as for kibbles.   The handle should be hinged at the top rim of the bucket.

(12)   Bulldog clips (12) for $^{1}/_{2}$-in. (12-mm) winding rope.

(13)   Bulldog clips (12) for $^{1}/_{4}$-in. (6-mm) concrete feed rope.

(14)   Bulldog clips (12) for $^{1}/_{8}$-in. (3-mm) plumbing rope.

(15)   Thimbles (six) for $^{1}/_{2}$-in. (12-mm) winding rope.

(16)   Thimbles (six) for $^{1}/_{4}$-in. (6-mm) concrete feed rope.

(17)   Thimbles (six) for $^{1}/_{8}$-in. (3-mm) plumbing rope.

(18)   Tumbler hooks (one) made of $^{3}/_{4}$-in.- (19-mm-) diameter steel, the link welded at the side.

Sinking and concreting tools

(19)   Miners' bars, 5 ft (1.50 m) long, made from $1^{1}/_{8}$-in.- (28-mm-) diameter steel, with chisel at one end and point at the other.

(20)   Trimming mattocks (two), 3 lb. (1.4 kg) weight, shaft 24 in. (60 cm) long.

(21)   Sinking mattocks (one), 5 lb. (2.2 kg) weight, shaft 24 in. (60 cm) long.

(22)   Miners' picks (two), 3 lb. (1.4 kg) weight, shafts 24 in. (60 cm) long.

(23)   Picks (one), 5 lb. (2.2 kg) weight, shafts 36 in. (90 cm) long.

(24)   Filling shovels (two), round-nosed; shaft not more than 24 in. (60 cm) long.

(25)   Mixing shovels (four), square-nosed; shafts 36 in. (90 cm) long.

(26)   Knapping hammers (five), $1^{1}/_{2}$ lb. (700 g) weight; shaft 10 in. (25 cm) long for breaking stone for concrete aggregate.

(27)   Sledge hammers (one), 7 lb. (3 kg) weight; shaft 24 in. (60 cm) long.

(28)   Sinkers' hats (two), of light-weight fibre or plastic.

(29)   Sieves (two), round, $^{3}/_{4}$-in. (19-mm) mesh, for maximum size of aggregate.

(30)   Sieves (two), round, $^{1}/_{4}$-in. (6-mm) mesh for minimum size of aggregate.

(31)   Sieves (two), round, $^1/_8$-in. (3-mm) mesh for sand.

(32)   Spare shafts (12), 24 in. (60 cm) long for mattocks and picks.

(33)   Head-pans (two).

(34)   Plumb bob (one).

Hand tools

(35)   Cutlasses or matchets (one).

(36)   Cold chisels (two), flat end; 9 in. (23 cm) long; of $^7/_8$-in. (22-mm) hexagonal steel; for cutting reinforcing bars, trimming shovels, etc.

(37)   Oil can (one), 1-pint (0.57-litre) capacity, for headframe-winding.

(38)   Pliers (one pair), side cutting, 8 in. (20 cm) long.

(39)   Wire brushes (two) for cleaning shuttering and tools.

(40)   Spanners (two), thread; box spanners for $^5/_8$-in. (16-mm) nuts; for dismantling and assembling headframe.

(41)   Spanners (two), locknut; straight spanners for $^1/_2$-in. (12-mm) nuts (shuttering assembly).

(42)   Spanners (one), shifting; maximum opening $1^1/_2$ in. (38 mm).

(43)   Mason's trowels (one), 9 in. (23 cm) blade.

(44)   Level (one), bricklayers'.

Locally made equipment (see Fig. 81, 82, pages 277 and 280)

(45)   Top plumbing rods (one set) : two rods 4 ft 9 in. (142 cm) long, $^5/_8$ in. (16 mm) diameter, mild steel, riveted together in the centre with a hook for fixing plumbing rope.

(46)   Long trimming rods (one set) : two rods 4 ft 6 in. (137 cm) long, $^1/_2$ in. (12 mm) diameter, mild steel, riveted together in the centre.

(47)   Short trimming rods (one set) : two rods 4 ft (122 cm) long, as for item 46.

(48)   Moulds (six) for precast concrete blocks $4 \times 4 \times 8$ in. $(10 \times 10 \times 20$ cm), with recesses.

(49)   Gauge (one) for curb undercut, made from $^3/_4$-in. (19-mm) mild steel rod.

(50)   Plumbing pegs (four) made from 1-in.- (25-mm-) diameter mild steel rod, two with $^3/_4$-in. (19-mm) holes, two with V's in the top, pointed lower ends.

(51)   Bosun's chair (one) of 1-in. (25-mm) timber for lowering on $^1/_2$-in. (12-mm) rope.

(52) Scaffold board (one) of 1-in. (25-mm) timber, 4 ft (122 cm) long, shaped to fit onto the ribs of lining shutters.

(53) Concrete scoop (one) for pouring concrete behind lining.

(54) Gauge boxes (two) of 1-in. (25-mm) timber. One (for gravel) $2^{1}/_{2} \times 2^{1}/_{2} \times 1$ ft ($75 \times 75 \times 30$ cm) internal dimensions, and one (for sand) $2^{1}/_{2} \times 2^{1}/_{2} \times {}^{1}/_{2}$ ft ($75 \times 75 \times 15$ cm) internal dimensions.

Porous Concrete

Concrete as laid in the ordinary way is a relatively impervious material. It is not quite waterproof because, however carefully it is mixed, placed, and tamped, there is always moisture in the pores between the grains of sand on setting; and, when this moisture eventually evaporates, minute hollows and channels are formed through which small quantities of water can percolate.

Concrete can be made more waterproof by adding chemicals to the cement or water during mixing; by covering the surface with an impervious coating such as bitumen or a sodium silicate solution; or by the use of vibrators during placing to shake the particles into position where they fit more closely each to the other, thus rendering the concrete denser and reducing the spaces between the sand grains. One or more of these methods may be used where watertightness is essential, such as in the construction of storage tanks.

There are, however, occasions in water-supply work where the opposite effect is desired, and concrete is made porous so as to allow water to pass freely through it. Typical cases are the sinking of caissons in which water must enter through the walls, and the laying of collection pipes in water-bearing strata where the maximum infiltration is required.

To render the concrete porous, sand is omitted; in other words, instead of a mixture of stone, sand, and cement, it is made of stone and cement only. Because of the omission of sand, this material is often referred to as " nofines " concrete. In normal concrete, the sand fills the interstices between the stones; in porous concrete, these interstices are left as voids after the mixing water has disappeared, and these voids act as waterways through which percolation can take place.

Obviously, this cannot happen without some loss of strength, as the individual stones composing the aggregate of the concrete are bonded together only at the points where they touch each other. Consequently, special precautions have to be taken in mixing, placing, and handling articles made of this material.

To start with, the stone used must be absolutely clean and free from any clay or loam. (This condition must be aimed for in any concrete, of course;

but with porous concrete it is doubly important.)   Secondly, the stone must be carefully graded.   A usual specification is that all stone must pass a $^3/_4$-in. (20-mm) sieve, but none should pass through a $^3/_8$-in (10-mm) mesh.   A 4 : 1 stone : cement ratio is usual.   The mixture should not be too wet; the minimum water content consistent with workability must be aimed for.   Tamping should not be excessive; moulds must not be struck too soon; and, above all, curing must be thorough.   For at least one week, —preferably for two—the concrete must be kept wet and shielded from the sun.   In the case of heavy caisson rings, at least three weeks should elapse between pouring and lowering into the well.   When these rings have to be transported by lorry from the casting site to the well-head, extra circular reinforcement is necessary.   Five rods instead of the usual two are recommended, with the top and bottom rods not more than 2 in. (5 cm) from the ends of the cylinder.

   If all these precautions are observed the porous concrete will be found to be as strong in use as normal concrete, and the convenience and efficiency of its use will repay all the trouble taken.

Annex 6

TYPICAL SPECIFICATIONS FOR A HAND PUMP

Basic information for a particular situation

(1) Inside diameter of riser pipe : $2^1/_2$ in. (6.4 cm)
(2) Static water level : 46 ft (14 m)
(3) Desired yield : 230 US gal. (870 litres) per hour
(4) Draw-down : negligible
(5) Free discharge above ground
(6) Type of power : hand operation
(7) Total depth of well : 60 ft (18 m)

Specifications

One hand-operated, heavy-duty, lift pump, for $1^1/_4$-in.- (3.2-cm-) diameter suction pipe and $2^1/_2$-in.- (6.4-cm-) diameter riser pipe, complete with operating top, steel pump rods and couplings, and pump cylinder, but not including pipes. The pump handle, fulcrum, and bracket to be of malleable iron, to withstand heavy usage, and the handle and fulcrum pins to be case-hardened steel pins. The pump pedestal to have a heavy steel brace below the handle, the stuffing box to have a long nut, and the pedestal to be tapped for $2^1/_2$-in.- (6.4-cm-) diameter pipe thread. The pump to include five 10-ft (3-m) lengths of $^7/_{16}$-in.- (1-cm-) diameter steel pump rod, complete with couplings. The pump also to include one light-pattern brass pump cylinder, of the extractable type, with $2^1/_4$-in.- (5.7-cm-) diameter bore, and 8-in. (20-cm) stroke, with cast-iron top connexion tapped for $2^1/_2$-in.- (6.4-cm-) diameter pipe, and with cast-iron bottom connexion tapped for $1^1/_4$-in.- (3.2-cm-) diameter pipe, the valve seats to be brass, with rubber-faced brass valves and followers, and the plunger to have double leathers.

Approximate cost in 1955 : US $45.00

Annex 7

CONSTRUCTION OF SMALL DAMS *

There is a peculiar satisfaction in producing, in an arid country, an artificial lake which will last throughout the dry season. On the face of it, this can be achieved by the simplest possible means—the throwing of an earthen bank across a wet-season watercourse—and at first sight this method of providing water appears to be simpler, cheaper, and more reliable than tapping underground sources by wells or bore-holes (see Fig. 85). This apparent simplicity has led to countless attempts by enthusiastic but ill-informed would-be dam builders; and while, admittedly, a number of these have proved to some extent successful, the large proportion of failures has shown that building a dam, whether large or small, is not a matter to be undertaken without forethought in planning, care in construction, and some knowledge of the basic principles of siting, designing, and building these structures.

Causes of failure

Before considering the basic principles, let us look at the ways in which a failure can occur. First, and most obvious, is the washing-away or breaking-down of a dam owing to its having insufficient strength to support the weight of water behind it. Only those who have seen the effect of such a break can appreciate the tremendous damage which can occur under these circumstances. An acre (0.40 hectare) of water—not a very big area—1 ft (30 cm) deep weighs over one thousand British or metric tons. Thirty-three acres (13.35 hectares) 24 ft (7.3 m) deep contain a million tons of water. Widespread devastation can be caused by the sudden release of such tremendous quantities of water.

Badly built concrete or masonry dams have been known to collapse suddenly and completely because of bad foundations, improper design, or poor quality of materials. Earthen dams may not go so suddenly, but the speed with which a small fault or breach can widen until practically the whole dam has gone can be really terrifying to see. The most common causes of such failures in earth dams are overtopping (the flowing of water over the top of the dam due to inadequate spillways); undermining, caused by water flowing below the embankment with consequent collapse of the

Fig. 85. SMALL EARTH DAM

Top of dam   Water level

Spillway

Section A - A

Drain pipe laid on firm foundation

Top of dam

1:2

Overflow pipe

1:3

Section B · B

Original contour

Water level

24 in

Final contour

Section C - C

B

A ————————————————— A

Final water line

Overflow

Soil for building

Final water level

Original contour at water level

C — · — · — C

Channel

Original contour at 24-inch depth

Dike

B

Spillway entrance around dike

Silting basin
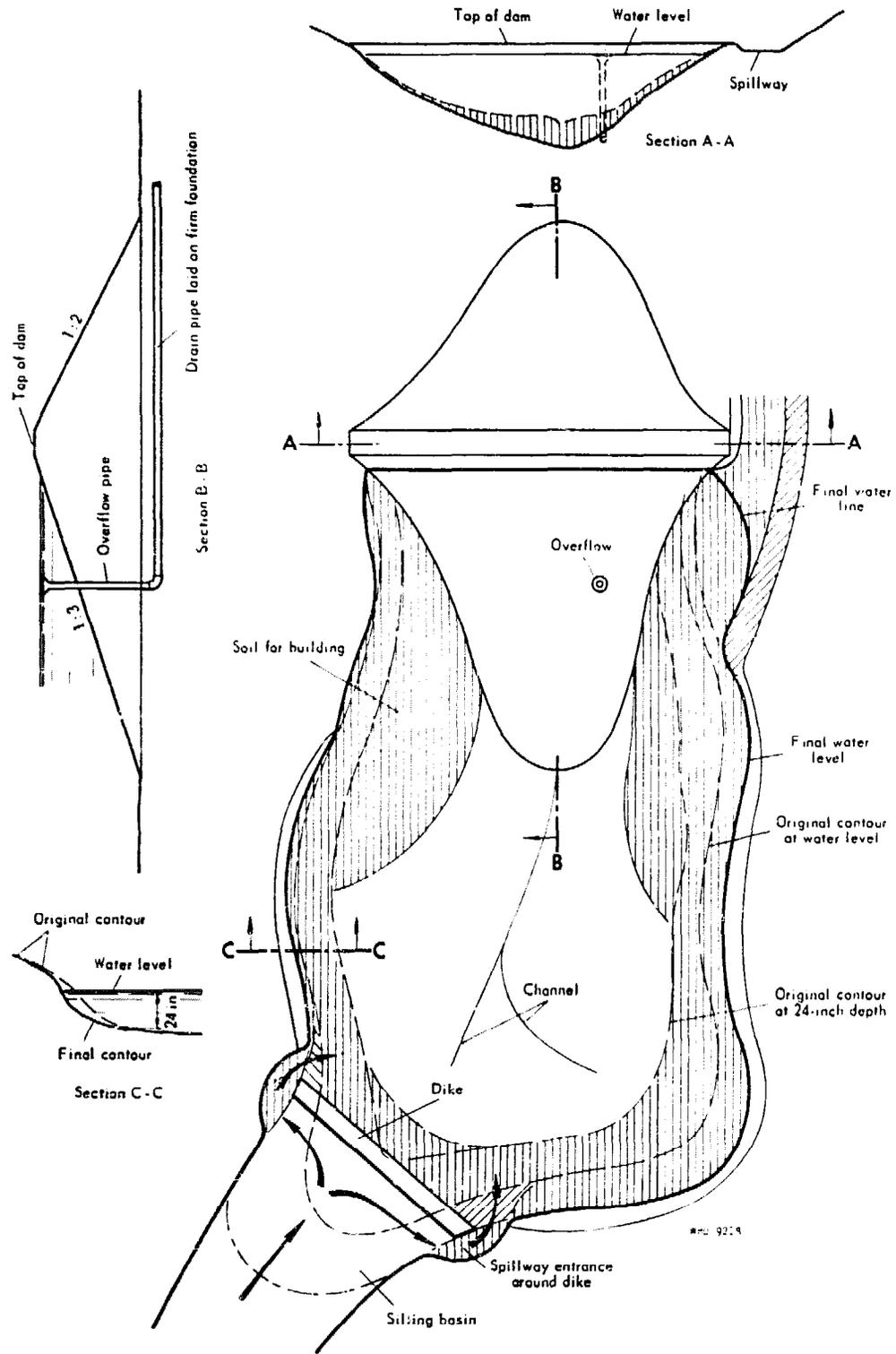
Shaded area indicates soil excavated

material above; fissures caused by shrinkage or by the use of wrongly chosen or badly compacted materials; percolation along tree roots which have not been properly cleared before construction commences or which have been allowed to grow later; weaknesses caused by erosion of the dam from heavy rain or other causes; and percolation through the dam, for a variety of reasons.

Even though a dam does not actually wash away, there are many other factors which may render it completely or partially useless for its purpose. If there is inadequate catchment area above the site, it will not fill. If the soil is of a porous nature, the water will soak into the ground and empty the reservoir. If sufficient allowance is not made for evaporation, the water will not last throughout the dry season. Sometimes, if the dam is not well sited the stream supplying it will change its course or cut itself another channel. If the stream flow contains much suspended solids and proper silt traps are not constructed, the dam may become useless in a few years owing to silting.

It may happen that, even if all these points have been taken care of, and the dam fills and retains its water throughout the year, the water is so polluted from town or village drainage or countains so many parasites as to be unfit for human consumption without expensive treatment. Intelligent siting and proper maintenance can help to minimize this risk.

Choosing a location

Having considered some of the faults, let us see how they can be avoided. First, it must be emphasized that time spent in investigating and comparing all possible sites to find the most suitable is never wasted. In the planning of a large dam, years may have to be spent in gauging of streams, compilation of meteorological data, surveys of catchment areas, and similar investigations; in the case of small schemes, very rarely do any records or surveys exist, and local knowledge usually proves a most inadequate substitute. Secondly, it must always be borne in mind that a dam is an engineering structure, even if made only of earth; and engineering and geological knowledge are both needed in its design. On no account should any dam holding more than about 15 ft (4.5 m) depth of water be attempted without qualified advice on both these aspects; and wherever possible a specialist should be consulted on dams of smaller size. In the event of failure, the best that can happen is the loss of the money and effort expended; in the worst case, loss of life and property may result.

The first step in dam building, then, is the choosing of a site. Five main points must be considered : there must be enough water to fill the reservoir; the reservoir must store the maximum quantity possible with the smallest dam practicable; the dam itself must be sited where it will have a sound foundation and an impervious reservoir, and where good

construction material is available; it must be sited where the water stored can be put to the best use; and it must be possible to keep it reasonably free from pollution.

Most rural dams are built across ephemeral streams—that is, streams which run for only a part of the year. This may mean a steady flow for some months or sudden flushes of water for a few hours only. In either case the amount of water reaching the site will depend largely on three factors : the amount of rainfall, the size of the catchment area, and the proportion of rain-water which runs off the ground, as distinct from that which soaks in or which is returned to the air in evaporation. The size and nature of the catchment are therefore of the utmost importance in deciding whether sufficient water will be collected to fill the reservoir.

There are very many factors which influence the " run-off " in the catch-ment area, and many highly complicated formulae which take these factors into account. The following " rules-of-thumb " may be taken as a general guide only.

The best type of catchment from the immediate run-off point of view is one with steep, rocky slopes where the rain, as soon as it falls, runs down-hill into a well-defined stream bed in which absorption and evaporation are at a minimum. The worst type is flat country with porous soil where a large proportion of the rainfall sinks to considerable depths and is lost as far as surface run-off is concerned, or where water is held in shallow pools or swamps with a consequent high rate of evaporation. On the other hand, excellent conditions may be found where there is a comparatively shallow depth of pervious soil overlying an impervious rock, and the rain-fall sinking into the top porous layer reappears lower down the valley as springs. The advantages of this type of catchment are that water held underground does not evaporate, is not easily contaminated, and is usually given up slowly. In other words, springs will continue to run for con-siderable periods after the end of the rains, thus needing a smaller reservoir to supply the same annual quantities. The water-holding qualities of this last type of catchment may be improved by the judicious planting of the right type of trees which, while returning the minimum amount of water to the air in transpiration, slow down the run-off and allow water to percolate downward into the underground storage. In any case, the presence of these conditions will be obvious from the fact that the stream from such a catchment will last well into the dry season.

Where the stream runs solely during and immediately after the rains, only the size and run-off of the catchment need be taken into account. A very rough guide to the quantity of water which can be collected from an average good area is to allow 5 acre-feet (6165 m³), e.g., 1 acre of water 5 ft deep, or 2½ acres of water 2 ft deep, for every square mile (259 hectares) of catch-ment for every inch (25 mm) of rain which falls. In other words, in an area having 20 in. (500 mm) of rain per year, a catchment area of three

square miles (767 hectares) should fill a reservoir of 30 acres (12 hectares) with an average depth of 10 ft (3 m). In rocky country this figure may be doubled; on porous soils, it will be greatly reduced. A lot will depend, too, on whether the rain falls in short, heavy storms or long, gentle showers.

After estimating how much water is likely to reach the proposed new reservoir, it is necessary to compare this with the amount which will need to be stored. The latter is not merely the amount which is required for use during the dry season, but must be sufficient to compensate for losses by evaporation and percolation.

Evaporation varies in different climates : in Northern Nigeria, it varies from $1/5$ in. to $1/3$ in (5 mm to 8 mm) per day during the dry season, and it is usual to allow from 5 ft to 8 ft (150 mm to 240 mm) per year for losses from this cause. Evaporation losses vary with other conditions also. An exposed site where wind continually ruffles the surface of the water into waves will lose more than a site sheltered by hills or trees; on the other hand, trees too close to the water may increase evaporation by drawing water from the reservoir through their roots and returning it to the air by transpiration through their leaves. The type of tree to be allowed near the reservoir is important : broad-leaf trees like the eucalyptus encourage evaporation, but needle-leaf trees like casuarina or conifers transpire little and may provide valuable windbreaks.

Percolation varies with the soil forming the floor of the reservoir, which is rarely completely impervious. Losses from this cause may tend to decrease in time as the floor seals itself with silt or organic and clayey matter settling out of the water.

It is desirable that the depth of the pond at the deeper end be at least 6 ft (2 m) if the water level remains constant, and about 8 ft (2.4 m) if the water fluctuates 1 ft (30 cm) more.

Assuming, then, that the catchment will produce enough water for the purpose required and that the approximate size of the reservoir necessary to store this water is known, the next is to look for a site where this size can be obtained with the smallest dam practicable. Sites should first be examined above the town or village to be supplied. Apart from minimizing the risk of pollution, the higher the reservoir, the less pumping will be required; and, if the dam can be sited at such a level that the water will gravitate from it to the points of consumption, then pumps may be unnecessary. However, it may be that, even if such a site is available, the supply main will be so long that the capital costs will outweigh the saving in pumping. Of course, in flat country the chances of getting a gravity supply will be small.

The most economical site will usually be in a steep-sided valley where the stream runs slowly, that is, a valley with a steep cross-section and a flat longitudinal section. The faster the ground rises at right angles to the stream, the shorter will be the dam; the gentler the slope along the stream

bed, the further upstream will the water be impounded, and the larger will be the area of the reservoir for the same height of dam.   There are certain particularly favourable conditions to watch for, notably a place where a broad valley suddenly narrows : a dam built at such a point will be of minimum length, and the broad valley above will provide the maximum storage.

Geological considerations

Having considered possible sites from the physical angle—the economy of building and the size of storage—the very important geological aspect next arises—the type of soil for the reservoir and dam foundations, and the material available for construction.   First let us look at some types of site which should not be considered.

Ground containing large boulders can be most attractive at first sight, particularly when the stream flows between two large rocks which look as if they were just made for abutments.   This type of formation is a trap into which many an unwary dam builder has fallen.   Only a short bank or concrete wall is required across the gap and water starts impounding upstream.   As soon as a head builds up, the water starts finding its way along the face of the rocks—along the " contact plane " between rock and earth—and either the water escapes through a number of fissures which it has produced, or the abutments themselves, apparently so solid, are loosened and—moving—allow the dam to collapse.   More obviously bad sites are those in permeable laterite, weathered or fissured bedrock, deep alluvial sands, and porous rocks such as loosely cemented sandstones, or gravels.

Good sites include those where basement rocks such as granite or basalt extend right across the valley at or near the surface, and places where there is a considerable depth of silty or sandy clay.   In the former site it may be more economical and certainly more permanent to build in concrete or masonry; the latter type of site is suitable for earth embankments.   Whatever the type of ground chosen, it should be closely examined by the digging of trial holes along the line of the dam.   Such trial holes may reveal fissures in the rock or unsuspected streaks of other materials in an apparently impervious subsoil.   If doubt exists, certainly—and even if there is no doubt, preferably—a geologist should be consulted at this stage; he may suggest forwarding samples for examination in a geological laboratory.   Such an examination should always be made if there is the slightest question concerning the suitability of the foundations, the material which is to be used for earth fill, or the material in the bed of the reservoir.

Clearing the reservoir site

Once the location of the pond has been selected, the proposed water lines should be marked with the aid of a level.   All trees, dead leaves and

branches, logs, stumps, roots, and brush should be pulled from the area to be submerged by water. In addition, a strip 15 ft (4.5 m) wide back from the water's edge should be cleared of all vegetation. It should be remembered that emerging as well as floating vegetation may harbour mosquitos, support pond scum, and clog spillways, as well as being unsightly.

Construction of dam and spillway

Having chosen a site and made sure that there will be enough water' that sufficient reservoir capacity can be obtained, and that the foundations are good, the next question will be the material of which the dam is to be constructed. As stated earlier, if a good rock foundation is present, then mass concrete, reinforced concrete, or masonry may be used. It is not intended here to go into the details of design of dams in these materials : this is essentially a problem for an engineering expert, and should never be attempted by anyone without the ability and experience to calculate the stresses and strains involved, and the strengths of the construction materials.

Before the consideration of the less involved design of earthen dams, a few words must be said on the most important subject of spillways. With a concrete or stone-built dam, water may be allowed to spill over the crest of the dam and flow over the downstream face in time of flood; but in an earthbuilt dam, such spilling must not be allowed to happen. This is the most fundamental rule of such structures : water must never, under any circumstances, flow over the top of an earthen dam. Consequently, an alternative channel for flood water must be formed clear of the dam and at such a height that when the reservoir is completely full the severest storm cannot raise the water level sufficiently for there to be any danger of " overtopping ", which is the quickest and most certain cause of dam destruction known. More will be said about the size and construction of spillways later, but from the beginning it must be emphasized that the spill-way is as important as the dam itself, and any consideration of the dam siting must take into account the spillway provision at the same time.

Spillways should be cut out of solid ground, clear of the dam itself. It is usually safer to construct two of these, one at either end of the dam. Frequently they are arranged so that one is slightly lower than the other to take overflows, the higher one acting as a safety valve in the event of an abnormal flood. Conditions vary from site to site, but a rule that should be adhered to rigidly is that, under the worst possible conditions, the crest of the dam must be at least 3 ft (90 cm) above the top water level passing over the spillway. Three feet (90 cm) is the absolute minimum which should be allowed; 5 ft (150 cm) is safer and should be aimed for wherever possible.

The spillway channels should be continued downstream well away from the " heel ", or downstream edge of the base, of the dam, so as to pre-

vent flood water which has passed over the spillway from eroding the dam itself. The longer these channels are the better, and it will usually be found possible to use the material excavated from them for dam construction.

The shape of the dam itself will vary with the material employed. A section frequently used is one with the downstream face sloping at 1 in 2 (two feet or metres horizontal for every foot or metre vertical rise); the upstream face, 1 in 3; and a 4-ft (122-cm) wide crest, or path, along the top of the dam (see Fig. 85, page 298).

For a dam which is required to hold 12 ft (3.6 m) of water at its deepest point, with a maximum depth of 2 ft (61 cm) passing over the spillways at flood time and a 5-ft (1.5-m) " freeboard " (i.e., height of crest over top flood-level), the width of the base of the dam would be calculated as follows :

Height of dam is 12 + 2 + 5 = 19 ft (5.8 m). Width of base is 2 × 19 (downstream slope) + 4 (width of crest) + 3 × 19 (upstream slope) = 99 ft (30 m). This is at the deepest point, and the base will narrow as the depth of water decreases towards the sides. The base of the same dam at a point where the ground has risen 7 ft (2.1 m) from the deepest point will be 2 × 12 + 4 + 3 × 12 = 64 ft (19.5 m). The crest should be maintained at the same width and level throughout the length of the dam, except that it is usual to allow a slight rise towards the centre to allow for settlement, though if proper compaction methods, as described later, are carried out, such settlement need be very little.

The first stage in constructing the dam itself is to work out the width of the base at various points along the length and to mark this on the ground with pegs. The whole of the area so pegged must then be excavated down until really solid ground is reached, and another foot (30 cm) should then be taken out so as to ensure that the structure is properly bonded into the solid ground below. The rougher and more irregular the bottom of the excavation is, the better. Any tree or other roots which may still remain at this depth should be removed completely. Under no circumstances should any stumps be allowed to remain in or near the pegged area. In large dams or dams built of porous materials, a cut-off trench (i.e., a trench running axially along the dam which will act as the foundation to a core wall) will be necessary; but this is a matter for engineering design. However, it may be noted that in the cases mentioned it is usual to build a central wall of concrete or puddled clay inside the dam to act a waterproof barrier. Such a core wall does not have the strength of itself to resist the weight of water, and is held in place by the earth embankment on either side of it, (see Fig. 85, page 298).

The next consideration is the material to be used in the dam. One of the best soils is a clayey material containing some silt of sand; if clay alone is used, it will tend to crack when dry and slip when wet; if too much sand is present, water may percolate through the interstices. A temptation to dump boulders or rocks inside the bank in the mistaken idea that these will help

" anchor " the dam must be resisted at all costs.   As far as possible the material used throughout the banking should be uniform; but, if any of the filling is at all doubtful, particularly as to porosity, it should be kept on the downstream face.   It is impossible in these notes to describe all suitable and unsuitable materials; as stated earlier, if there is the slightest doubt, a geologist should be consulted or samples should be sent for laboratory analysis.

In building up the dam, three fundamental rules must be observed : first, the material must be spread in continuous, shallow layers 4-6 in. (10-15 cm) deep over the whole area; second, it must be kept damp but not too wet; and, third, each layer must be well compacted before the next layer is added.

At no time should any part of the dam be built more than 3 ft (91 cm) above any other part, and vertical joints should be consistently avoided. If the soil is being carried by head-pan or basket, then it is a useful method for the pans of earth to be dumped in lines from one end of the dam to the other, and for the labourers carrying them to walk over and to tread-in the heaps already deposited.   The soil should be damp enough to retain a foot-mark, and if it is dry, sufficient water should be pumped or sprinkled on the deposited material to ensure this.   On the other hand, if construction is carried out in the wet season and the soil is wet enough for a foot-mark to fill with moisture, then precautions must be taken to prevent water from lying on the surface of the filling.   This is best done by keeping the centre line of the dam higher than the edges at all times during construction so that rain runs off both upstream and down.   Provided that the moisture content of the filling material is kept right and that the layers are shallow, sufficient compaction will often be obtained from the feet of the labourers; but additional compaction is desirable and may be carried out by other labourers using punners of iron or timber.   Another method frequently used on village dams is the driving of cattle from end to end of the dam after each day's work.   Often suitable earth material for construction of the dam may be obtained on the spot from the area of the pond and from the spillway site.   Excavation should be carried out below the expected water line, and care should be taken to avoid pockets or holes in the ground at a lower level than the opening of the scour pipe.

Protection against erosion

After the dam has been built to its final size and shape, it must be protected against erosion of two sorts—rain action and wave action.   Rain falling on the upstream slope above water level, on the dam crest, and over the whole of the downstream face will tend to wash away the surfaces and weaken the dam.   The cheapest and simplest way to prevent this is by the planting of suitable creeping grass, such as dhub or bahama varieties.

Tufts should be avoided, and any species of grass which forms such tufts must not be allowed on sloping surfaces, as these will tend to divert rain-water into channels, causing gully erosion.

The best time to plant grass is at the beginning of the rains—a little before, if it is possible to arrange for regular watering until it is well established. Before planting, the surface should be covered with topsoil and manure. The top few inches of the ground excavated for the spillway channels and the dam foundation should have been stacked on one side for this purpose, and it should be well mixed with animal manure or composted refuse. It is no good trying to get grass to grow quickly if it is planted directly into the filling material, and it is important that it should establish itself quickly so that it will not be washed out in an early heavy storm. The long shoots of the creeping grass should always be planted in horizontal rows along the length of the dam, never up and down the slope. If the downstream slope is long, with a consequent large catchment of rain-water, it may be well worth while to pave the lower part of the bank with rough stone pitching to stop erosion of the heel of the dam and to get the water away quickly.

On the upstream face, pitching or other protection will always be necessary to prevent damage from waves. Wave action will always be present, and the damage done to the dam will depend on the size of the waves, which, in turn, will vary with several factors. The longer the " fetch ", i.e., the length of uninterrupted water surface upstream of the dam, the higher will be the waves; and this will be more so if the prevailing wind blows down the full length of the water. Much erosion from this cause can take place immediately above and below the water line, and it is a safe rule to pave the whole of the upstream slope to a height of at least 2 ft (60 cm) above top water level with rough stones as heavy as a man can conveniently carry, hand-placed with smaller stones wedged into the interstices. The remainder of the slope above the " pitching ", as this type of stone paving is called, should be treated by planting grass as described for the downstream face.

After planting, care must be taken to prevent people from walking up and down the grass slopes. Foot-paths diagonally across a sloping bank inevitably cause erosion, as rain-water flowing down the bank collects in a channel on such a foot-path and quickly cuts a gully. If access up and down the dam is absolutely necessary, it should be at right angles to the slope, and the path should be paved or steps should be formed with rough stones.

Installation of scour pipes

In almost every case the expense and trouble of installing a scour or drain pipe and washout valve will be well worth while. Without such a washout

system it is impossible to regulate the level of the reservoir during times of flood or in the event of damage; the dam cannot be emptied for repair or inspection except by pumping, and silting cannot be controlled.

When the water from the reservoir is drawn off from below the dam to a pumping or treatment plant or gravity main, by means of a draw-off pipe passing below the dam, then the scour will usually be combined with this pipe. In many small village schemes the water is withdrawn upstream of the dam, and any scour system will be independent of the draw-off. This system consists of a pipe leading from the deepest part of the reservoir to a point well downstream of the dam, with one or (better) two valves controlling the flow through this pipe.

The scour pipe must not be laid through the earth filling of the dam itself, but in a trench excavated into the solid ground either below the dam foundations or to one side of the dam. Frequently it passes under the spillway. A pipe 8 in. (20 cm) in diameter will suffice for a pond of less than 2 acres (0.8 hectares) in area.

Mention has been made earlier of how water will pass along a contact plane such as that between an iron pipe and the surrounding ground; a scour pipe, being at the deepest point of the reservoir, is a particularly vulnerable spot for such " contact plane " percolation. For this reason certain precautions are taken during the laying of the pipe. Wherever possible a puddle flange—that is, a collar of metal fitting tightly to the pipe and projecting for about a foot (30 cm) all round—is fixed; but, in any case, the trench in which the pipe is laid should be filled with concrete for at least that part of its length which lies below or alongside the dam itself. In at least two places this concrete must be increased in depth and thickness to form a key with the surrounding ground and, at the same points, extra concrete should be added above the trench for the same purpose.

The main scour valve must be well bedded in concrete and fixed in the pipe in such a position that it is always accessible, whether the dam is empty or full and water is running over the spillway. This is one of those obvious points which can easily be forgotten, and an operator who wishes to open the valve may be faced with a spillway channel running 2 ft (60 cm) deep in flood water to cross before he can reach the control.

It has occasionally happened that a scour valve, left partially or fully opened during flood time, has become jammed by a piece of wood or stone wedging beneath the " gate " of the valve, and therefore could not be shut. Without emptying the reservoir it is not possible to open up the valve for repairs; and, consequently, unless there is an alternative means of shutting off the water in the scour pipe, all the storage in the reservoir escapes, usually at the end of the rains when there is no chance of refilling it. The obvious precaution is to install two valves at different points in the scour pipe so that, if one jams, the water may be cut off by the other until it is convenient to clear the obstruction. If for reasons of expense

or other cause a second valve cannot be fixed, a substitute called a " monk "
is fitted to one end of the scour pipe.

This monk consists of a concrete chamber about 4×3 ft (122×91 cm)
internally extending from the end of the pipe upwards to a height slightly
above the top flood-water level inside the reservoir.   The concrete of the
chamber is well bonded to the concrete surrounding the scour pipe with
reinforcing wires.   Across the narrower width of the chamber, at right
angles to the direction of water flow, boards can be inserted in grooves cut
into the concrete walls for that purpose so that in an emergency these
boards, pushed into place one above the other, form an almost watertight
barrier, which can easily be completely sealed with clay or other suitable
material.   In some very small dams, where the cost of imported materials
is a major consideration, no scour valve is included; and reliance is placed
solely on one or two monks to retain the water in the dam.

Scouring should start as soon as water begins to flow over the spillway.
After a period of full scour, with the valve fully opened to clear away silt
immediately round the outlet, the valve should be partly closed and an
endeavour made to regulate the flow to waste to that amount would nor-
mally escape over the spillway.   In other words, the water level is main-
tained as high as possible behind the dam without actually overflowing.
Conditions vary from scheme to scheme, of course; but it is good practice
to keep the scour running for as much of the wet season as possible.   Not
only does this counteract silting and circulate the water in the reservoir, but
it also keeps the level to safe limits at a time when sudden storms may
cause a dangerously high rise in water level.

Deepening the reservoir's edges

The edges of the reservoir should be deepened by 2 ft (60 cm) or more in
order to discourage the growth of emerging vegetation and weeds and,
especially, to discourage mosquito and snail breeding in shallow waters
along the reservoir's perimeter (see Fig. 85, page 298). It may also be desir-
able, in small schemes, to throw a small dike across the drainage entrance
to the reservoir to create a silt trap.   The dike may be built where the
water is about 2 ft (60 cm) deep, and may project 1 ft (30 cm) above the
reservoir level.

Size of spillway

The calculation of spillway sizes is one of the most controversial subjects
in dam design, and numerous formulae based on different methods of flood
discharge calculation are available for large works.   For the kind of dam
which we are now envisaging, however, the sole information on which
such a calculation will be made may well be the memory of the oldest village
inhabitant, who has recollections of a flood when the water came " almost
to that tree ".   A sifting of local evidence will invariably produce contra-

dictory information, and the would-be designer is left to " estimate ",
i.e., to guess, from the evidence of debris on the banks, water marks on
rocks, and the like, how high the water rises in the stream in normal flood
times.

Find out, then, as accurately as possible, how high the stream rises
at the wettest time of the year, and estimate the width of an equivalent
stream running 2 ft (60 cm) deep.   Allow extra width according to whether
last year was a particularly wet, dry, or average year, and then double your
result to allow for an exceptionally heavy storm.   This is not mathematics,
nor is it engineering : if you can get an engineer to work out your spillway
width, you should do so.   If not, the figure you have arrived at by the
method above should be regarded as the minimum size of your spillway
or spillways; if in any doubt whatever, increase the width.

The width you have arrived at for your spillway is the width at the
crest, or highest point, which will normally be at a point in line with the
dam itself.   This spillway crest should be lined with stone or concrete to
prevent erosion.   The channels leading to and away from this crest need
not be paved, but precautions must be taken, particularly in the down-
stream channel, to prevent damage.   Normally the channel should widen
a little immediately below the crest to prevent " backing-up " of the flood
water, and the first part of the channel should be a fairly steep but smooth
slope, so as to get the water away from the crest rapidly.   It may be neces-
sary to pitch this steep section with rough stone.   Further downstream
the channel should flatten gradually, and lead into the stream well below
the dam with as smooth a flow as possible.

It is a common practice to build into the spillway crest vertical flash-
board supports, frequently made from old railway lines.   They should be
concreted well into the ground with about 2 ft (60 cm) projecting upwards,
the flat or " web " section downstream, and about 3-4 ft (90-120 cm) apart.
Flash-boards—boards about 1½-2 in.)(4-5 cm) thick, 9 in. (23 cm) or 1 ft
(30 cm) in width, and of a length exactly to fit between the supports—can
be slid into place one above the other so as to form a wooden wall about
2 ft (60 cm.) high across the spillway crest.   This can be made waterproof
by means of clay, hand-placed between the boards.

The purpose of flash-boards is to increase the capacity of the reservoir at
the end of the rains after all danger from sudden storms has passed; but it
must be remembered that the spillway is a safety valve protecting the dam
from flood damage, while flash-boards have the effect of counteracting this
safety factor.   The first and absolutely vital rule, when using flash-boards
therefore, is to appoint a responsible person who will remove them imme-
diately should a " freak " or out-of-season storm occur.   Many small
dams have been lost through neglect of this rule.   By making the total
depth of the flash-boards equal to the maximum flood discharge over the
spillway crest, the " freeboard " of the dam in flood times (i.e., the height

of the dam above maximum flood level) is equal to the freeboard in the dry season (the height of the dam above static water level). This, as said earlier, should be at least 3 ft (90 cm), preferably 5 ft (1.5 m).

It is obvious that flash-boards must be removed from the supports before the onset of the rains each year. It is better to take them out as soon as the water recedes during the dry season, and to store them flat and out of the sun; otherwise, when required the following year, they will be found to have warped and will not fit into the supports.

Other construction points

The following are some miscellaneous points to be borne in mind when constructing dams :

All sloping ground surfaces, particularly those artificially graded, are liable to erosion in heavy rains. This applies particularly to such points as the edges of spillway channels, stream side banks immediately below the dam, etc. These vulnerable points should be protected by diverting rain-water in properly constructed channels, by terracing, and, where necessary, by pitching.

TYPES OF FINANCIAL STATEMENT
FOR SMALL WATERWORKS *

Detailed Cost Breakdown

A detailed cost breakdown is calculated for the total yearly production of water.

Production costs

Water pumping labour
Water pumping electricity (or other fuel)
Other production expense
Depreciation
Insurance
Interest
Allocated administrative expense

Total production costs

Distribution costs

Operating expense
Maintenance
Depreciation
Insurance
Interest
Stores expense

Total distribution costs

Other operating costs

Customer accounting and collecting
Administrative and general

Total other operating costs

Total all costs

Total water revenue

Net income to surplus

Statement of Operating Expenses

The following operating expenses are tabulated for both monthly periods and the year to date.

Production expense

Operation supervision
City water pumping labour
Miscellaneous station labour
City water pumping, electricity, and fuel
Station expenses
Maintenance of structures and improvements
Maintenance of city wells
Employees' welfare and expense plant
Treatment labour
Treatment supplies and expense
Maintenance of structures and improvements
Maintenance of treatment equipment

Total

Distribution expense

Operation supervision and engineering
Operation of lines
Services on customer premises
Street repairs, labour and material
Maintenance of mains
Maintenance of valves and equipment
Maintenance of services
Maintenance of meters
Employees' welfare and expense—district

Total

Customers' accounts and collecting

Customers' contracts, meter reading
Customers' billing and accounting

Total

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* Reproduced from Haley, J. L. (1957) *J. Amer. Water Works Ass.*, **49**, p. 21, by kind permission.

Administrative and general expense

- Sales promotion expense
- Sales : general, officers and executives
- Other general office salaries
- Expense of general office salaries
- General office supplies and expense
- Special services
- Legal services
- Insurance
- Miscellaneous general expense
- Maintenance of general property
- Rent
- Rent on office equipment
- Stores expense

Total

Profit or Loss Statement

The profit or loss statement features, in addition to the following items, figures on the number of customers served by the utility, and the amount of water pumped, sold, and lost. The number of customers for that month is compared to the number for the same month in the previous year. The amount of water pumped, sold, and lost is tabulated for that month, for the year to date, and for the 12 previous months to date. The net profit or loss is drawn up for that month and the year to date.

Operating revenue

- Water sales
- Water for city
- Interdepartmental sales—plant use

    Total

- Water taps
- Service charges
- Miscellaneous revenue

    Total operating revenue less charges
        for water for city

    Net operating revenue

Operating expense

- Production expense
- Distribution expense
- Customer collection and accounting
- Administrative and general

    Total

- Depreciation

        Total operating expense
        Net operating profit

Other expense

- Bond interest expense
- Interest on contracts

Services to city

- Labour and material—fire hydrants
- Other services to city

    Total

Net profit or loss

SOME PRACTICAL HINTS ON THE OPERATION AND MAINTENANCE OF SMALL WATER-SUPPLY SYSTEMS IN RURAL AREAS *

Health and Welfare of Waterworks Personnel

Mention has been made in the text, particularly on page 171, of the need for safeguarding the quality of the water supply. Quite obviously, then, the first precaution to be taken in waterworks operation is to prevent persons suffering from communicable diseases from coming into contact with the water supply. Under most circumstances this is easier said than done. Labourers cutting grass and cleaning wells and reservoirs, attendants cleaning filters and operating pumps and machinery, fitters at work on the mains and connexions, painters working in steel tanks, etc.—all are in indirect contact, if not with the water itself, at least with surfaces and materials which will later touch the water. Every effort should therefore be made to avoid employing workmen suffering from diseases transmissible through water. It should be remembered, however, that a man can be a carrier of disease (such as typhoid fever) capable of infecting the water supply without showing any symptoms of the disease himself. It is desirable that all waterworks personnel should be medically examined once a year, preferably just before the annual scouring and cleaning operations. Anyone suffering from diarrhoea, ulcers, or open sores should be sent home or given other work until he recovers.

Furthermore, strict instructions should be issued and rigidly enforced against allowing unauthorized persons to enter pumping stations, treatment works, etc. This particularly applies to food sellers; but the habit of all and sundry of wandering through waterworks compounds on the grounds that these are public property with unlimited access should be most severely discouraged. At the sites of open reservoirs there should always be watchmen to prevent bathing, washing of clothes, indiscriminate urination, depositing of refuse, and other harmful practices in the vicinity of the water.

The welfare of waterworks employees is important in its own way. Many welfare measures which at first sight seem merely to be " pampering " the workers will be found to increase the efficient running of the works.

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* Prepared from a personal communication from Mr. W. E. Wood, Chief Water Engineer. Ministry of Works. North Region, Nigeria

Provision of a house near the works for the pump attendant, for example, will usually be an advantage, as the man will be available quickly in the event of an emergency. The purchase of a bicycle for him and for the distribution attendant, and the installation of telephones at their private houses (wherever possible), will often be found to be good investments. The provision of protective clothing such as raincoats to workers whose duties are outdoors in bad weather as well as good will save more than its cost in work done and sickness avoided. In a pumping plant a rest-room for eating meals and storing clothing not only will benefit the workers using it, but also will help to keep the works tidy and prevent the pumphouse from being used for these purposes. There should also be facilities at such places for drinking-water, hand-washing, and latrine accommodation. Such practices as dipping a dirty tin into a clear water tank to get a drink and washing up food containers on a pumphouse floor would seem to be too unhygienic to mention, but all these things have been known to take place. A small supply of bleaching powder should be available at every works for disinfection purposes.

Pump Maintenance

Correct maintenance of pumps requires trained staff. A common error is to assume that anyone with some mechanical knowledge, possibly obtained by driving a lorry or truck, is fit to take over the running of a pumping station. It is not suggested, however, that on small works it is necessary to have a skilled fitter or mechanic capable of dismantling and carrying out major repairs to his engines. Indeed, in all but the most exceptional cases it is recommended that the pump operator should not attempt to carry out major repairs, as it has been proved over and over again that in many cases of serious breakdown the trouble can be traced to a spanner in well-meaning but semi-skilled hands converting a simple repair job into a major overhaul.

The chief needs in pump operation are thorough understanding of, and conscientious attendance to, the lubrication of engines and pumps, the use of the correct grade of oils and grease, and keeping the machinery and pumphouse clean. In addition, according to the type of machinery installed, the attendant should be able to change and adjust belt-drives; to clean plugs on a petrol engine (but not, under any circumstances, the injectors in a diesel engine); to clean fuel filters, air filters, and cooling systems; to pack a gland (with the correct grade of packing); to change cup leathers on a reciprocating pump; and to carry out similar minor servicing. He should be able to report in writing and keep records of fuel consumption, hours worked, quantity pumped, etc., and, above all, he should know when to ask for skilled assistance if symptoms of trouble (e.g., worn bearings) occur.

Supply and Distribution System

The yearly round of maintenance will include the activities described below.

Supply structures

Wells, spring catchments, and cisterns should be inspected and if necessary, cleaned out. Any algae or other growths in these and on concrete weirs or other submerged structures should be scrubbed off with wire brushes, and the walls should be treated with bleaching-powder solutions (strength 50 p.p.m.). Feeder pipes should then be flushed. In every well-designed scheme, wash-out valves are inserted at the low points. These valves should be opened full bore with the system at maximum pressure, and water should be allowed to flow until it has ceased to contain any turbidity, colour, or suspended matter. The valves should then be shut and left so for a few minutes and then re-opened. If the water is again coloured, this process should be repeated until it is perfectly clear. If there are no wash-out points, fire hydrants may be used for flushing. If neither exist, then some should be inserted for the cleaning purpose.

Storage tanks, both concrete and steel, should be thoroughly cleaned down. They should be allowed to empty to a depth of about one foot. The outlet is then closed and men armed with new (and this is important —*new*) brushes scrub down the walls, columns, ladder, etc. The remaining water is then slowly run to waste while the cleaners keep it agitated by sweeping the floor towards the outlet. When it has been drained off completely, the whole of the interior is scrubbed down with bleaching powder which has been dissolved in buckets to the consistency of a thin cream. The solution should be vigorously applied and worked into any surface cracks or roughnesses in the concrete, and left for an hour or so before being washed off with repeated applications of clean water. It will usually be found necessary to fill the tank and run the contents to waste before putting it back into operation after this cleaning.

Provided that facilities for bathing after work are provided, no harm should come to the men working with the bleaching powder solution; but clean water should always be handy in case anyone should get a splash in the eye, which should be immediately rinsed.

The interior of steel tanks should be carefully examined to see how the bitumen coating is standing up. It should be possible to estimate a year ahead when repainting will become necessary so that all preparations can be made for this to be done at the next annual cleaning. The length of time between paintings will depend on many factors, particularly the chemical characteristics of the water, and will vary from two years to seven or eight; five-yearly intervals are common. The material used is normally

a quick-drying bitumen paint with non-inflammable base specially manu-
factured for the interior of water tanks.   It is important that it should dry
in a few hours, impart no taste to the water, and give off no fumes which
might harm the painters working inside a closed tank under a hot sun.
Detailed instructions on painting steelwork are outside the present scope,
but it may be said that the use of wire brushes for removing all loose
scale and old paint and the cleaning of rust spots are absolutely
essential.

Distribution system

Particular care should be exercised in flushing dead-ends of distribution
mains.   It is in these ends that most solids are deposited.   These solids
consist of many substances, such as minute algae growths, the results of
chlorine action on oxydizable matter in the water, particles of bitumen or
other pipe coatings, oxides of metal resulting from the action of acid waters
on the pipes, and fine sand or other suspended matter which may have been
carried through the treatment works.   Most of these substances are " inert "
and harmless in themselves, but are very unpleasant when issuing from taps
in the supply.   If they are allowed to accumulate in the mains, a sudden
change of pressure, such as is caused when a section is shut off for any
reason, or when a fire hydrant is opened, will stir up these solids, which
will turn the water into a black or brown mud and persist in the system until
they either are flushed out or resettle.

Another trouble, which can occur in the dead-ends of even the purest
supply, is the breeding of thread worms of various sorts.   These are most
unpleasant when they issue from taps and are most difficult to get rid of,
as they travel along the mains to points far distant from their breeding-
ground.   Very high doses of chlorine are necessary to kill them, which
makes the water practically undrinkable; and, when killed, their bodies
remain in the system and must eventually be dealt with.   In unfiltered water
leeches can also present a similar problem.   The remedy for both these
organisms is regular and thorough flushing.   In a large works with plentiful
supply, this should take place monthly; but even in the smallest works it
must be done completely at least once a year.

When new mains are laid, or when repairs or extensions are carried
out to existing systems, it is almost impossible to prevent contamination
during laying.   In the wet season, there will usually be dirty water in the
trenches; in the dry season, dust will enter the pipes; and, whatever the time
of year, the open ends of a pipeline under construction present an irre-
sistible temptation for children to push sticks and stones up the pipe.   This
last, apparently frivolous, hazard is nevertheless a very real one; and there
have been several cases of pumps being damaged by stones, and of sticks
and other similar bodies becoming wedged in bends and necessitating the

taking up and re-laying of part of the main. Adequate watching during non-working hours and the plugging of open ends after the day's work reduce this risk considerably, but it should always be assumed that a new length of main may contain foreign objects and will certainly be contaminated. The following precautions should therefore be taken.

At the " far end " of the main (the end remote from the source of supply), before the installation of the wash-out valve or connexion to the next length, the pipe should be left open and the water allowed to run full bore for a short time—a temporary length or two of pipe being connected to prevent the water from flooding the trench. When it has been flushed in this manner, the main is completed; and, through a hydrant or air valve, or by opening a pipe joint at the opposite (" near ") end, bleaching-powder is inserted in the following approximate quantities : for a 3-in. (8-cm) main $^1/_4$ lb. (113 g) of powder for every 100 m (330 ft) of pipe; for a 4-in. (10-cm) main, $^1/_2$ lb. (226 g); and for a 6-in. (15-cm) main, 1 lb. (453 g). Water is then run through until the chlorine in solution comes out of the far end, which can be detected by its smell or by an orthotolodin test. As soon as the chlorine appears, the main is shut and allowed to stand full of the solution for at least 12 hours, at the end of which time it is flushed out until all trace of chlorine has disappeared. Each successive length of pipe should be treated in this fashion until the whole system has been disinfected, and only then should it be put into public use. When standpipes or services are connected to the length of main being treated, a part of the chlorinated water should be flushed through each.

Meters

Meters really deserve a section on their own. They are probably the most delicate pieces of machinery in a small waterworks, and are, for various reasons, among the most difficult to maintain. Specially trained staff and equipment are necessary to overhaul and test water meters. Despite the delicacy of the mechanism, a well-constructed meter rarely suffers from accidental damage; but careless and wilful damage, particularly to the glass covers, is all too common. Lazy and corrupt meter readers and dishonest consumers account for most of this damage, and steps must be taken to combat this, or revenue will suffer badly. One solution lies in the type of meter chosen. There are many types as well as many makes of small meter, and the following are some of the differences.

First, the basic principle of the meter varies. Leaving aside the question of large meters such as one used to measure the flow in mains, about which a few words will be given later, meters may be of positive or inferential types. Positive meters are the more accurate and expensive. They are rarely used for consumers' connexions because of their cost. The principle on which they work is such that every drop of water which passes through is

actually measured, either by the displacement of a piston inside a cylinder or a smaller cylinder revolving eccentrically inside another. They are used where extreme accuracy of widely varying flows is required; they are particularly accurate in dealing with very small flows. In the inferential type, the water flowing through the meter spins a metal or plastic wheel which is fitted with blades like a miniature water-wheel. The speed of rotation varies according to the quantity of water passing through the meter, and the number of revolutions is transmitted through a system of gears to a dial face. The gears are similar in many ways to those used in the positive type, but the accuracy of the " fan " or water-wheel is less than that of the revolving cylinder.

The inferential meter is more liable than the positive type to certain forms of trouble. For instance, if for any reason a main is emptied or a negative pressure occurs when there is a burst or a fire hydrant is opened, water and air may be drawn back through the meter, which will operate the dial in a reverse direction. When an empty main is filled up and a tap is open on the metered connexion, the fan will spin at a high rate, giving a false record—sometimes amounting to hundreds of gallons. Again, although the meter mechanism is protected by a perforated metal or gauze disc, it sometimes happens that a small particle of stone or other foreign matter lodges against this disc and alters the angle of the water jet which impinges on the fan, giving a reading either too high or too low. Such inaccuracies do not occur with the " positive " type.

In both types, however, a part of the gear mechanism works inside the water. and a water containing over-much iron, hardness, or other impurities may corrode or choke this delicate machinery.

Meters may be of the " wet-dial " or of the " dry-dial " type. In wet-dial meters the water circulates not only through the meter body itself, but also above and below the dial. which runs at all times completely submerged. Above the dial a heavy piece of pressure-resisting glass holds back the water pressure while allowing the dial to be read from outside. The glass is protected by a hinged flap of brass which is lifted only when the meter is being read. In the dry-dial type a watertight gland below the dial keeps the latter running in an air space. The glass above a dry dial is much thinner as it serves merely as a dust trap and as protection from tampering; this glass is covered by a hinged flap, as in the wet-dial type.

Normally the dry-dial type is somewhat easier to read. particularly if the water is at all coloured or contains any lime which may be deposited on the underside of the thicker glass. The dry-dial type is more liable to tampering because the glass may be broken without interfering with the service. The chances of accidental breakage of the glass are remote, because of the brass cover previously mentioned; but in practice the number of glasses which have to be regularly replaced is extremely high, and this can only be accounted for by either the meter readers' or the consumers' de-

liberately smashing them in an attempt to turn the dial backwards. Only an outside check can determine when this occurs.

With the wet-dial type such damage is obvious as soon as it happens, as water escapes under full pressure, flooding the immediate area and cutting off the supply to the connexion. The water must be turned off and a replacement meter installed before the service can be resumed. This, coupled with the fact that the glass is extremely difficult to break on account of its thickness, reduces " accidental " damage almost to the vanishing point; and, for the reason, wet-dial meters are recommended for all house connexions. further advantage is that there is no gland below the dial : this gland in dry-dial type is an occasional cause of trouble, since on becoming n it may allow water to pass.

The e two types of dials—the " decimal-dial " type and the " direct reading type. The former consists of a number (usually seven) of small circular dials, each reading from 0 to 9 and representing units, tons, hundreds. A complication is that each dial reads in the opposite direction from the previous one, and some instruction and practice are necessary before this type is read accurately by the average meter reader. The " direct reading " type, on the other hand, records the quantity by a series of figures in line which are very much easier to read. Despite this advantage the first type is usually preferred, as the internal gearing to the dials is simpler, less liable to wear, and more reliable in operation.

When a meter is sent out from the factory, it is sealed with a lead disc, and this seal should never be broken except in a properly equipped meter-repair workshop, where another seal will be fixed after repair and test.

The position of the meter normally marks the limit of the water authority's responsibility, everything on the " house " side of the meter being deemed to belong to the consumer, whose liability it is to carry out all repairs to that section. For that reason it is usually found that the meter is as near to the boundary of the property as possible. From the main in the street a connexion is taken off and, immediately this crosses the fence line dividing the consumer's plot from the roadway, a stopcock and then a meter are inserted in the service pipe. From then onwards the consumer takes all the responsibility : he also has a responsibility towards the meter in that he is usually paying rent for it directly or indirectly, even though the authority itself owns, maintains, and is responsible for the condition of the meter. There is usually (and should be always) a clause in the agreement making the consumer liable for external damage, whether accidental or wilful, to the meter, however caused; and a replacement fee is charged before a damaged meter is changed.

In fairness to the consumer, then, every endeavour must be made to protect the meter from outside interference, particularly from children. Wherever a building is constructed adjacent or near to the highway, it is often better to fix the meter inside the house rather than in the ground out-

side.   Meters can be obtained to fit on to vertical pipes, and a convenient place can often be found on the wall of the house sufficiently high to be out of reach of children.   The stopcock will be fixed immediately below (i.e., on the " mains " side of) the meter, and the authority will be expected to maintain the short additional length of pipe up to this.   This added responsibility is a comparatively small one and will usually be found to be more than compensated for by the avoidance of damage to the stopcock and meter, the ease of access to these items for reading and servicing, and the avoidance of the necessity for a stopcock and meter boxes.   In some communities, particularly in Moslem countries, there are objections to the meter's being placed inside the compound where meter readers may not enter, but there will almost always be an entrance room or a portion of the compound where such objections do not apply.

Where the buildings lie some distance back from the roadside there is usually no alternative but to set the meter underground just within the compound, and in such cases a concrete- or brick-lined pit is constructed with either a concrete slab or a cast iron-cover.   These pits are often very crude, but a little extra care in their construction will usually be found well worth while in the long run.   The meter pit should be properly lined and watertight; big enough to allow the meter to be fixed and replaced without breaking down the walls; insect-, scorpion-, and snake-proof; and supplied with a cover big enough to allow sufficient light to enter for the meter reader to see the dial easily, and heavy enough to deter children from lifting it. A cast-iron cover with the frame cemented to the pit may seem an expensive luxury, but it will save a lot of maintenance trouble, particularly if it can only be opened with a special key held by the meter readers.   The stopcock should not be fixed in the same pit as the meter—a small length of 4-in.-(10 cm-) or 6-in.-(15-cm-) diameter pipe placed over the cock with a small box or slab at the surface is all that is necessary to make this easy, but not too easy, of access.

Materials

Fuel

Fuel will usually be petrol (gasoline) or diesel oil in rural water-supplies, though electricity may be the motive power in a few cases.   Small engine-driven pumps are usually rather inefficient for a variety of reasons, as a result of which fuel consumption is fairly high.   As a guide, a small diesel engine will consume about 0.23 litres, or quarts, of diesel oil per hour per horsepower, and a petrol engine about 0.3 litres, or quarts, of petrol per hour per horsepower.   An electric motor will use about one unit per hour per horsepower.   Lubricating oil consumption may be estimated (in a reasonably new machine) to be about $\frac{1}{15}$ of the fuel consumption in either a diesel- or petrol-driven engine.

Both petrol and diesel oil have to be stored against the dangers of fire and theft, and provision for locked stores for this purpose should be made in the construction of the works. In a large scheme storage will usually be in underground tanks, from which the fuel is drawn by means of a pump which can be locked; but in small works the fuel will be kept in drums in a fire-proof fuel store, from which drums it will be taken by means of a gallon or litre measure to the fuel tank of the engine). The drums should be kept almost horizontal, on racks known as " stillages ", at a convenient height above the floor to allow the measuring jug to stand below the tap on the end of the drum. Storage on stillages is particularly important in the case of diesel fuel which, on standing, deposits a fine sediment which must be thrown away when the drum is almost empty; otherwise, it would clog the filters or injectors on the engine. Petrol does not throw a sediment, but a certain amount of evaporation takes place, particularly in the tropics, however carefully it is stored and handled. For these reasons it is usual to allow a 2 % loss on petrol stocks and a 1 % loss on diesel stocks. It is much better to write off these amounts than to allow the attendants handling the fuel to " work off " these inevitable losses by allocating short measures or falsi-fying their records. An accurate account of fuel consumed, compared with hours worked and quantity pumped, is a most valuable check on the condition of the plant as well as on the timekeeping of the attendants.

The conditions under which fuel is stored in bulk are fully laid down in statutory regulations prevailing in a country and will not be enlarged upon here; but two points will be mentioned : the need for thorough ventilation, and the absolute necessity of enforcing the " no smoking " rule. It is worth adding that nothing else whatever should be kept in the fuel store, and the store itself should be kept absolutely clean. Diesel fuel particularly, if spilt on the floor and not cleaned up, will make a slippery mess which can cause accidents, and will also attack the concrete of the floor, causing it to break up.

Little need be said about electricity as a fuel except that all men working in the vicinity of the installation must know and observe the safety regula-tions, and that no one other than a qualified electrician should ever attempt to repair or interfere with any wiring, switchgear, or motors.

It will frequently be a condition of the electricity supply that a lower rate is charged if current is not used during the " peak " hours, or time when the normal electric load is at its maximum (usually from about 6.30 p.m. to about 9.30 p.m.). The suppliers may insist that current be controlled by means of a time switch : if not, and if reliance is placed on hand switching by an attendant, precautions must be taken to ensure that only in an ex-treme emergency (e.g., a fire, when extra quantities of water need to be supplied urgently) shall the motors be used during the prohibited period.

Chemicals

As stated earlier (see page 181), the most common form of chlorine used in rural water supplies will be either bleaching-powder (chloride of lime) or a high test hypochlorite (HTH).

Bleaching-powder, or chloride of lime, is a powder which is supplied in drums or in jars according to the quantity required. It must be stored in a dry, cool place, particularly once the container has been opened, as it deteriorates rapidly in the presence of heat or moisture. One method of use is to dissolve a certain quantity in a tank of water, stir thoroughly, and then leave the solution to settle for 24 hours. The clear liquid is then run off into a second tank, from which it is fed into the treatment plant; the sediment is disposed of, and another mix is then prepared. As the solution in the tank is made up to a constant strength, a convenient method is to have a container made holding the exact amount of powder needed for one tankful of water. This is filled as required from the bulk store; naturally, with variations of quantity pumped, the daily requirements will vary some-what, but it will usually be possible to judge the quantity made up at one time to suit one day's supply.

As with all materials, a careful check must be kept of the amount issued daily, and the amount remaining in store must at all times be sufficient to continue treatment until a new supply is available. A minimum stock should be specified; and, when the amount in store has fallen to that level, a new supply must be ordered. When new stocks arrive, it is important that the amount remaining of old stock be used before the new supply is started upon; otherwise, the old material will deteriorate through excessive length of storage.

Bleaching-powder and HTH can both be painful if they get into the eye or into an open wound. Immediate flushing with plenty of water is the most usual, and probably the most effective, treatment in such a case. In general, no chemicals of any kind should be allowed to remain long on the skin without being washed off.

Spare parts

At a pumping station or treatment plant it is most important to build up a stock of spare parts, not only because of the desirability of spreading the expense of their purchase over the first few years, when little repair work should be necessary, but also to ensure that breakdowns can be dealt with without delay. In this way, when a mechanic or inspector is making a routine maintenance visit, he can carry out minor repairs with spares ready to hand; and the system does not incur the cost and delay of a return visit.

Some suggestions for spares to be held are listed below. These are the minimum necessary; others may be recommended by the maintenance engineer according to the difficulty of obtaining stores quickly from local

agents or central stores. Whenever an item is used, it must be replaced immediately.

(1) For petrol engines—sets of plugs, gaskets, gasket-sealing compound, spare magneto, petrol-feed pipe, air and oil filter elements, carburettor float, spare washers for petrol-feed pipe, and carburettor timing chain.

(2) For diesel engines—sets of injectors, gaskets, gasket-sealing compound, washers, filter elements, fuel pipe, timing chain.

(3) For electric motors—sets of fuses, brushes, insulation tape.

(4) For pumps—cup washers, valve rubbers or leathers, belts and belt fasteners, grease nipples.

With many machines—engines, pumps, chemical-dosing apparatus, etc.—a supply of spares recommended by the manufacturer for the first two years' operation will have been provided when the machines were installed. These " two-year spares " will probably include the items recommended above. They, and/or the items above, should be kept in a locked box or cupboard with a list of its contents on the inside of the lid or door; and, whenever any item is removed, the fact should be entered on the list and immediate steps should be taken to replace it.

Spares for mains and distribution systems are less easy to define; but, as a general rule, provision should be made for several burst pipes of each different-sized main—say, a minimum of half a dozen pipes of each diameter. Detachable joints, where used, should be kept in similar numbers, plus an odd valve, air valve, hydrant of each size, together with a few bends and tees. Where cast- or spun-iron pipes are in use, some double collars, together with lead wool for jointing, should be kept.

Normally the basis of the mains spares will consist of items left over from the construction, when a percentage extra will have been ordered to deal with contingencies such as breakage; but, unlike plant maintenance, mains maintenance is usually heaviest during the first few years of a scheme's life. The first wet season is a severe test for asbestos cement mains when trenches, which may have been insufficiently consolidated during filling in, begin to settle and inadequately bedded pipes snap. Even cast-iron pipes which have successfully stood up to test may, after some months' use, develop hair cracks because of bad handling.

Consequently, from the first taking-over of a scheme, a minimum stock of each item should be laid down; and, once the stock has been thus built up it should not be allowed to fall below that figure without immediate re-ordering of replacements.

Tools and miscellaneous equipment

With regard to the pumping station and chemical-dosing equipment, unless there is a particularly skilled fitter or mechanic in charge, the rule should be to have the minimum number of tools possible. Reference has

been made earlier to the damage which can be done by a spanner in unskilled hands. Only the simplest repairs should be carried out by the operating staff. A plug spanner, a pair of spanners to fit the fuel-pipe lines, hammer, screwdriver, and pliers for belt fixing and minor jobs about the station, are all the tools which will normally be required. An oil can, grease gun, fuel measures (gallon, half-gallon, or litre), lubricating oil measures (pint, quart, or litre), watering-can and bucket, head-pan, chemical measures, shovel, etc., will all be required—and, when chemicals are used, a balance or pair of scales.

Tools should be hung in a rack on the wall so that it can be seen at a glance whether anything is missing. It should be noted that when an inspecting mechanic visits for maintenance or repairs he will have his own kit of tools with him, and it will not be necessary to provide equipment for dismantling or repairing the plant. It is useful, however, particularly in isolated works, to have a set of shear legs, ropes, chains, and pulleys, for lifting the engine or pump unless (as is preferable) a girder and chain block has been provided in the building of the pump-house for this purpose.

Two other items should be provided at the works—fire extinguishers and a first-aid kit.

Fire extinguishers may merely consist of buckets containing sand or water, chemical extinguishers, and such other equipment as asbestos blankets. Buckets are, of course, the simplest; but, unless proper precautions are taken, they will be found to be missing when an emergency occurs. They should, therefore, always be painted red and hung on hooks on a wall; and disciplinary action should be taken against anyone found misusing them. Special fire buckets are obtainable with convex bottoms, which will not stand upright when placed on the ground and consequently are less liable to improper use. All staff at the works should know the basic principle of using sand and water (never to use water on oil or petrol or near live electric wires), and buckets must be regularly emptied and refilled. This should be a weekly job, allotted to one particular man on a particular shift. If water is not emptied and replaced regularly, it will breed mosquitos; if sand is not similarly treated, it may cake solid and be useless when required. In any case, such buckets almost always become repositories for cigarette ends, bits of rag, and other rubbish if not regularly cleaned.

Chemical extinguishers are much more efficient than buckets, and are a good investment when expensive machinery is to be protected. They will normally be of one of three types : soda-acid, foam, or carbon tetrachloride. The soda-acid type is a general purpose extinguisher to protect buildings, offices, and stores other than fuel stores, it must not be used on oil or petrol fires or on live electric wires. The foam type is suitable for oil, petrol, or other liquids since its action depends on spreading a sheet of foam over the flames which smothers them; the oil will not float as it would on water or on the liquid from a soda-acid extinguisher. A carbon tetrachloride extinguisher is normally a small cylinder with a hand pump which

sends out a stream of liquid which can be used on electrical apparatus safely, since it is a non-conductor, and can also be used on machinery and on small petrol and oil fires. It will not do damage to plant, which sand, similarly used, would do. One point, however, must be watched : carbon tetrachloride is a very effective cleaner and will take grease stains out of clothes; consequently, when a fire occurs, it may well be found that the extinguisher has been emptied a few drops at a time over a period by the workmen at the station, who find out the properties of the liquid in a remarkably short time.

Chemical extinguishers must be regularly examined and must be emptied and refilled at least once a year. A minimum of two recharges must be kept in store at all times and replacements ordered whenever refilling takes place. It is a useful practice to have a fire drill occasionally—certainly not less often than once a year—and to let the pump attendants put out an actual fire of oily waste or other scrap with the extinguishers so that they may really understand the instructions for use. The equipment should then be washed out and refilled. Nothing is more dangerous than to rely on chemical extinguishers which have become empty because of evaporation, leakage, or corrosion, or which cannot be operated in time owing to the lack of knowledge of the man operating them.

An extinguisher should always be kept in the same place, preferably on a proper wall bracket, so that it may be found immediately. It is good practice to mark on the wall behind it the successive dates of recharging, so that the engineer in charge, when inspecting, may be sure that this has been regularly done.

Asbestos blankets are not very usual on small stations, but are extremely useful in smothering fires in electrical gear or petrol engines.

Reference has been made to first-aid boxes. These should be of the simplest type since it is most unlikely that a skilled man will be available to treat any accident. There should, however, always be wound and burn dressings; and one man on each shift should know enough to be able to apply these in case of emergency. Iodine or other disinfectant should be provided for minor cuts or scratches, with some lint or cotton wool for application purposes (bandages may be a source of danger unless they are kept absolutely clean). A pair of tweezers for getting out splinters is useful. The best of all first-aid measures is a tap of clean, running water under which cuts or grazes can be thoroughly washed before disinfectant is applied. Strict instructions should be given that all major injuries, minor cuts which fail to heal, and, above all, anything affecting the eye (such as particles of metal or splashes of chemical) should be examined by a medical officer as soon as possible. In the event of an accident involving unconsciousness or broken bones, the patient should not be moved and a doctor should be summoned immediately.

Other items required at the works are : brooms, cleaning rags, detergent powder, brass polish, and soap; hurricane lamps with a stock of kerosene

for emergency lighting, and a good torch; and paint and brushes for touching up machinery and pipework (as distinct from major decorations previously mentioned). Grass cutters and gardening tools for the waterworks compound are also desirable, unless these jobs are to be done by outside labour. On open reservoirs a raft or small boat with suitable tools for weed-clearing will be required.

Large meters and recorders will not be repaired or serviced by the local pump attendants, but a supply of charts and ink will be necessary for weekly or daily replacing. The authority will usually be asked to keep a stock of mercury and some spare pens so that, when the visiting inspector wishes to make replacements, the material is handy.

Tools and equipment for the distribution system will need to be more comprehensive than those on the supply works and will depend on the size of the scheme and the materials used. Pipes on a village scheme will normally be of asbestos cement, cast or spun iron, and galvanized iron. Joints on asbestos cement pipes will be of the flexible variety, incorporating rubber rings and one or more detachable sections. Special spanners are required to fasten these joints, and will have been supplied by the manufacturers with the pipes initially; sometimes chain tongs will be needed as well. To cut small pipes a hacksaw will be necessary; only on large-sized pipes is any special cutter needed. Cast-iron mains will have either detachable joints similar to those used with asbestos cement, or " spigot and socket " joints which must be jointed with lead—either lead wool or molten lead. For lead-wool joints supplies of spun-yarn lead wool will be required, with sets of caulking tools; for molten or " run " joints, the same tools will be needed with the addition of a brazier, melting pot, ladle, and collar. Molten lead is rarely used nowadays. Galvanized iron or steel pipes will only be met with in small diameters and can be jointed with " foot-print " spanners; red lead and a threaded union are the only materials used. A threading tool (stocks and dies) will also be necessary after the pipe has been cut with a hacksaw. For cutting larger galvanized-iron mains, as well as for cast iron, special cutters consisting of a number of hardened steel wheels mounted in a chain or circle of steel are used. Valves, hydrants, etc., will need a set of spanners for dismantling and fixing. Greasy packing for renewing the stuffing boxes and glands of these parts of the system will also be required.

For making connexions to the mains, a tapping machine will be needed. In the better types of machine, mains can be tapped and ferrules inserted while the system is under pressure; but, in a small scheme, this is often considered an unnecessary luxury. When the mains are of asbestos cement, a steel saddle will be required for each connexion. Whatever material is used for piping, a pipe vice will be necessary as well as a complete set of fitter's tools, which will include stocks and dies, pipe wrenches, hacksaw, spanners, and other small tools. Most of these will last for years, apart

from expendable items like cutter wheels, hacksaw blades, and dies, which wear out; but a small sum should be allowed each year for replacements. There is no worse economy than to allow a man to do slow and shoddy work through using worn-out tools; this applies to all parts of a scheme, of course, and not just to the distribution side.

Among the miscellaneous items which will also be required on the distribution side are picks, shovels, crowbars (for opening up trenches — sledge hammers and chisels will also be required if the ground is rocky), axes, hurricane lamps (red for warning traffic of an opened trench and white for inspectors at night), torches, valve keys, a portable standpipe and some lengths of hose for flushing, and—a worthwhile luxury—a lockable hand cart for carrying the former items from job to job.

General Cleanliness

The cleanliness of the buildings, machinery, and equipment of a works is usually a good indication of the efficiency and care with which it is run. Consequently, every encouragement should be give to those responsible for keeping the works in a neat and presentable condition. Regular interior decoration of buildings, the issue of cleaning materials (cotton waste, brass polish, detergent powder, etc.), and provision of a reasonable amount of labour for keeping compounds tidy may all appear to be " luxuries " at first sight; but they pay handsomely in the increased cleanliness and efficient running of the water supply, provided that the workers can be persuaded to use them and take pride in the appearance of the works. If this pride is not present, and if the man in charge has to be forced to use the cleaning materials provided, then it is better to have a change of staff; if the outside appearance is neglected, it is quite safe to say the more important processes which are not seen will be neglected even more.

* * *

These notes are by no means complete instructions on maintenance and operation; indeed, they only touch on certain aspects which would need a complete book to describe adequately. However, given keen employees, adequate supervision, and an awareness of the need for absolute cleanliness of the purified water at every stage from the works to the consumer, experience will soon fill in the many gaps. Provided that a regular supply of adequate quality and quantity of water is maintained, the consumer will be satisfied; and his initial and invariable reaction, on receipt of his first bill, that the cost is far too high for the service he receives, will be overcome. After all, the consumer is the man who pays for the water, and to satisfy him must be the prime object of every water-supply scheme.

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51	3	4			page 28	pages 27-29	
62			8		**Q** = Depth of water in well	**Q** = Depth to water table	**P** = Pump
67	4	6			81 ft	79 ft	
87	2	4			1/100 in.	1/64 in.	
141	3	4			B	A	
154	2	16			3.785 m³	3785 m³	
163	1	9			8550 US gal. (32 362 litres)	6300 US gal. (23 850 litres)	
169			66		F = Static head G = Hydraulic gradient	F = Hydraulic gradient G = Static head	
176				VII (col. 1)			Size of drains
180	4	4			classified	clarified	
181		1			(mg/litre	(mg/litre)	
189	1	7			3.6 litres 4 gallons	2.7 litres 4 US gallons	
200			73		**a** = Effluent **b** = Supply **c** = Overflow **d** = Drain	**Aa** = Effluent **Bb** = Supply **Cc** = Overflow **Dd** = Drain	
205	3	14			or	of	
207	1	2			7-in.	7½-in.	
213		28			× 16.70 m	=16.9 m	
214		15 24			537 93 045	597 99 040	
215		26 30			ehe 749 × 150 1 + 321 × 15	the (749 × 150) + (321 × 15)	
216		6 25 27			2.4 ft 275 m (902 ft) (0.3360 c.f.s.), or 151 US gal. per minute.	3 ft 480 m (1574 ft) (0.336 cubic foot per second or 151 US gal. per minute)	
218			79				Measures are in centimetres.
242	1	3			16-litre	18-litre	

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Page	para.	line	fig.	table	FOR	READ	INSERT
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266					1½-in. pipe... and 2-in. pipe... Gallons per 24 hours	1½-in. pipe... and 2-in. pipe... Million gallons per 24 hours	
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269					4-in. pipe... and 6-in. pipe... Gallons per 24 hours	4-in. pipe... and 6-in. pipe... Million gallons per 24 hours	
278	2	2			$^3/_8$-in.- (10-mm-)	$^5/_8$-in.- (16-mm-)	
		4			1.42 m	1.45 m	
281	5	3			2½ × 2 × ½ ft (75 × 61 × 15 cm)	2½ × 2½ × ½ ft (75 × 75 × 15 cm)	
285	3	3			93.5 cm 101 cm	94 cm 117 cm	
		10			1 ft (30 cm)	1 in. (25 mm)	
286			83		Caisson ring... Key to hold rod in position 1′0″ from lower end	Caisson ring... Key to hold rod in position 1″ from lower end	
290	4	4			65 mm	63 mm	
	5	3			p.s.i. (6.3-7.0 kg/cm^2)	per square inch (12.5-14 metric tons per cm^2)	
292		28			1-1½ lb.	1½ lb.	
293		20			4 ft 8 in.	4 ft 9 in.	
		21			$^3/_4$ in. (19 mm)	$^5/_8$ in. (16 mm)	
		29			$^3/_8$-in. (10-mm)	$^3/_4$-in. (19-mm)	
307		5			2 ft 60 cm	2 ft (60 cm)	

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