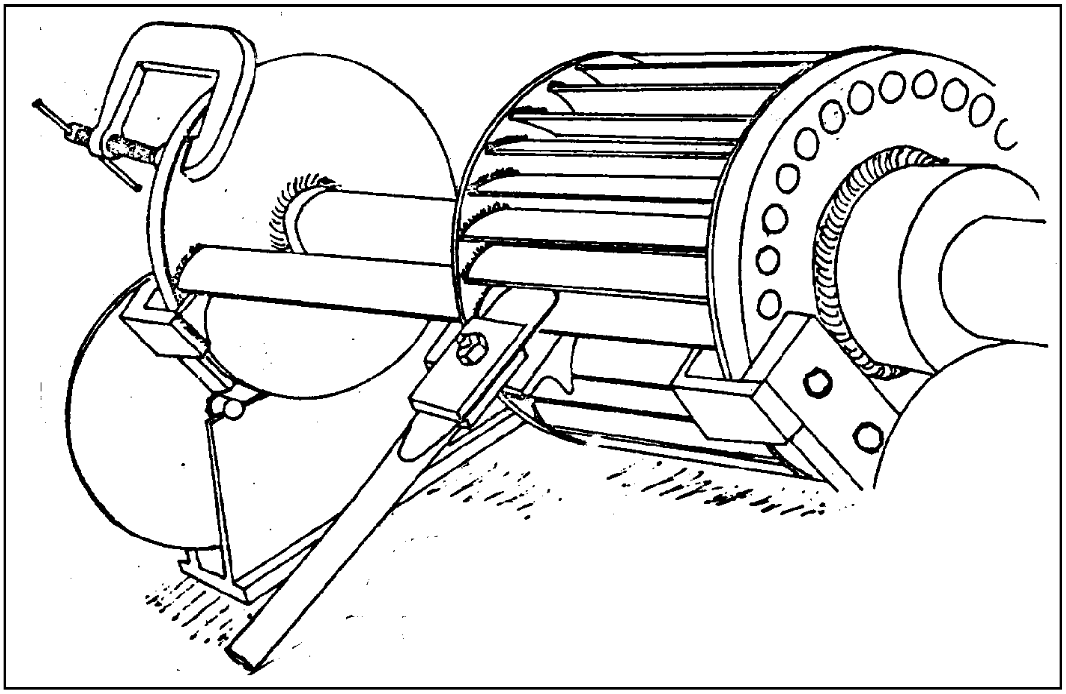

Energy: Water

For 2000 years, waterpower has been harnessed to do useful work. Waterwheels played a vital role in early industrialization in Europe and North America, powering a wide variety of decentralized manufacturing and processing enterprises. The steel water turbine provided more power at a given site than the waterwheel, and in the U.S. many waterwheel-powered mills were converted to water turbines in the late 19th and early 20th centuries. Blacksmiths and foundrymen produced the turbines and modified the designs during this period of great innovation and profitable production. Water-powered mills produced:

"... such household products as cutlery and edge tools, brooms and brushes ... furniture, paper ... pencil lead ... needles and pins ... watches and clocks, and even washing machines .... For the farm they turned out fertilizers, gunpowder, axles, agricultural implements, barrels, ax handles, wheels, carriages. There were woolen, cotton, flax, and linen mills ... tannery, boot and shoe mills ... and mills turning out surgical appliances and scientific instruments."
—**Renewable Energy Resources and Rural Applications in the Developing World**

The use of water power in the People's Republic of China has reflected the same pattern, with first water wheels and then turbines being built in great numbers as power demands increased along with technical production capabilities. By 1976 an estimated 60,000 small hydroelectric turbines were in operation in South China alone, contributing a major share of the electricity used by rural communes for lighting, small industrial production, and water pumping.

With the rising cost of energy in the United States today, small hydroelectric units are returning in large numbers. Generating stations along New England rivers *are being rehabilitated and put back into operation. The number of companies making small waterpower units has jumped. The U.S. Department of Energy has estimated that 50,000 existing agricultural, recreational, and municipal water supply reservoirs could be economically equipped with hydroelectric generating facilities.*

In developing countries, the potential for small hydropower installations has never carefully been measured. Past surveys of hydropower potential have focused on possible sites for large dams, as small hydroelectric units were considered uneconomical or ill-suited to the goal of providing large blocks of electric power for cities, industrial estates, or aluminum production. With the rapidly increasing costs of energy, however, the economics are now much more favorable for small hydroelectric units, which are also well-suited to the needs of small rural communities, and do not bring the degree of environmental disruption associated with large reservoirs. Many small units do not require reservoirs at all, and use small diversion canals instead.

The success of waterpower installations can be greatly affected by forest conservation practices in the watershed above. Rapid deforestation brings high rates of soil erosion and subsequent rapid silt filling of reservoirs behind dams. At the same time, greater rain runoff causes increasingly violent floods that threaten hydropower installations. During the months following the floods, low water flows are likely to reduce generating capacity. A program to protect the watershed and the construction of a diversion canal may be necessary to prevent damage to a small waterpower installation.

The first requirement in estimating the potential for a small waterpower site is to measure the flow in a stream during medium and low flow periods, and determine the high water level during flooding. **Low Cost Development of Small Water Power Sites** *is one of several publications that give good stream flow measurement instructions.*

For the construction of very small earth dams, the useful but out-of-print booklet **Small Earth Dams** *may be copied at an appropriate technology documentation center. Also of interest is the soil-cement sandbag technique for low dam construction employed by Los Gaviotas appropriate technology group in Columbia.*

Waterwheels still have certain advantages for rural communities in the South. The best use of these slowly turning (about 20 rpm) devices is in direct mechanical applications. They can be constructed of locally available materials (e.g., wood and bamboo) by village craftspeople, and they can pump or lift water and perform a variety of important crop processing tasks. They are well-suited to the small crop production of small farmers. Existing irrigation channels and small streams offer many potential sites at which the civil engineering works expenses can be minimized.

Industrial Archaeology of Watermills and Waterpower *is one of several publications that offer valuable insights into the design and evolution of waterwheels.* **Design Manual for Waterwheels** *contains important figures for the design of overshot waterwheels.* **Overshot and Current Waterwheels** *and* **Water Power for the Farm** *are useful references that were used in rural extension efforts in the 1930's and 1940's and have been recently reprinted.* **Watermills with Horizontal Wheels** *and* **Waterpower in Central Crete** *describe in detail the vertical-axis, horizontal wheel, stone flour and corn mills once widely used in Europe and Asia, and still used in large numbers in mountainous countries such as Nepal.* **MultiPurpose Power Unit with Horizontal Water Turbine** *gives details of a new Nepalese steel watermill that is proving to be very popular.*

The rapidly turning water turbine, made of steel or cast metals, can deliver a lot of power (e.g. 10-50 kw) from a very small unit, and is much better suited than the waterwheel to the task of producing electricity. Turbines can also be used for direct mechanical applications; they are more efficient than waterwheels, but cannot be made with local materials. The reader interested in water turbines will find **Micro-Hydropower Sourcebook** *to be the outstanding general reference book for developing countries. Several reports and sets of engineering drawings are included on the cross-flow turbines that have been successfully built in Nepal. These turbines are built to a standard diameter, with blades cut from steel pipe, and they can accommodate a range of head and flow conditions.*

The dissemination of large numbers of small waterpower devices is a challenging task. A very interesting successful experience in this regard is described in **Nepal: Private Sector Approach to Implementing Micro-Hydropower Schemes**.

Micro-Hydropower Sourcebook: A Practical Guide to Design and Implementation in Developing Countries, MF 22-541, book, 250 pages, by Allen Inversin, 1990, $29 North America, $20 elsewhere (airmail extra) from NRECA, 1800 Massachusetts Avenue N.W., Washington, DC 20036, USA; also from ITDG and TOOL.

The most thorough reference available on small hydropower for developing countries, this book can be used as a primer for those wishing to undertake such projects. The author has personally visited and compiled the stories of many of the most successful small hydropower efforts.

"There are few publications available to serve as a guide to those implementing (micro-hydropower projects with a capacity of less than about 100kw). Some of these publications deal primarily with larger small-hydropower plants, leaving developers of micro-hydropower sites with few options but to reduce in scale the approaches and designs which are appropriate for large plants. Consequently, such publications tend to encourage the use of approaches and designs which do not take advantage of the unique factors encountered when implementing plants at the 'micro' end of the small-hydropower range, factors which must be considered if this resource is to be harnessed cost-effectively. Other publications are incomplete, leaving out, for example, any but cursory mention of power canals, while a survey of micro-hydropower plants around the world would indicate that such canals are used at a vast majority of sites.

"On the other hand, there is a wealth of experience in developing micro-hydropower sites which has been gained over the last several decades. But those implementing these schemes often have little time or inclination to document their efforts and, therefore, what they have learned cannot serve as a foundation on which others can build. By means of (this book, the author has gathered) information relevant to those implementing micro-hydropower schemes, preparing more complete descriptions of the many aspects of planning and implementation, and documenting some of the experiences around the world."

Included are good presentations of the measurement of head and flow, stream flow characteristics, site selection and layout. The civil works (canals, diversion and intake structures, etc.) are given considerable attention, as they can be very costly. Turbine types are reviewed, along with coupling options (direct, belt and chain drives, gearboxes). Electrical vs. mechanical power, load controllers and flow governors are also discussed.

"It is probably the experience of many individuals working in rural villages that electricity, especially for lighting, is a frequently sought-after amenity. But, at the same time, it is also clear that, unless the villagers are actually using kerosene for lighting, the financial resources to pay for this amenity are not available. The advantage of generating hydro*mechanical* power is that it forces a focus on mechanical uses of power which probably already exist in a rural community and which normally generate income. Such activities include the milling of grain, the hulling of rice, the expelling of oil from seed, the saw-milling of timber, ginning of cotton, the pulping of coffee berries, and the crushing of sugar cane. A plant generating mechanical power to directly drive agro-processing or workshop equipment has, therefore, a better chance of being viable as well as of being replicable elsewhere in the region."

Highly recommended for use in developing countries. Readers in industrialized countries will find this a valuable supplementary reference.

Micro Hydro Electric Power, Technical Paper No. 1, MF 22-531, book, 46 pages, by Ray Holland, 1983, £3.95 from ITDG.

This booklet contains a basic introduction to the technologies and economics of small-scale waterpower plants. Readers intending to build plants will need to refer to other entries in this section, especially the **Micro Hydropower Sourcebook**.

Micro-Hydro Power: Reviewing an Old Concept, MF 22-515, booklet, 43 pages, by Ron Alward, Sherry Eisenbart, and John Volkman, 1979, National Center for Appropriate Technology, out of print.

This technical manual, while aimed at those considering installing small hydroelectric systems in the U.S., presents the key considerations in so clear a step-by-step manner that it would be a useful resource for the individual or small community in any region. Most useful as a companion text to more technical reference works.

Industrial Archaeology of Watermills and Waterpower, MF 22-511, book, 100 pages, Schools Council, 1975, Heinemann Educational Books Ltd., out of print in 1985.

This well-illustrated book provides a very good summary of the history of waterwheel development. The reasons for design improvements are discussed. This will allow the reader to better judge what materials and designs are needed for a particular application. For example, in the early 19th century, a very large slow-running waterwheel would develop high torque on the wooden main shaft, which might cause it to break. This was solved in two ways: by using iron shafts, and by using power drives off of the rim of the waterwheel (the main shaft then had only to be strong enough to support the wheel). Smaller waterwheels, for example, do not necessarily need these more expensive design elements.

By 1850, the British had built a number of very large industrial scale waterwheels, producing 65kw to 190kw of power, and ranging from 7m to 21m in diameter. Some of these waterwheels were kept in operation for 100 years. Such waterwheels would likely be very expensive to build today; but smaller wheels in the range of .3 to .5kw built locally in the rural South may be economically viable in many places.

Options for different installations are discussed: water course layout, types of wheel construction, bucket design, mechanisms for flow control, and gearing systems (belts, wooden teeth, iron gears) to take the power off the wheel and run it to the equipment.

The second half of the book is a guide for teaching students about waterwheels. This shows how to measure water flow in a stream, figuring torque on the waterwheel shaft assuming a certain wheel rpm, and calculating horsepower. Several working models can be used to illustrate principles. A brief but informative section on water turbines is included.

Those who want to design waterwheel installations will find this book helpful with its background information and 200 drawings and photos. However, the design formulas (for number of buckets, bucket depth, wheel width and diameter, etc.) that were well-developed by 1850 are not included and will have to be found elsewhere (for example, in **Design Manual for Waterwheels**).

Small Scale Hydropower Technologies, MF 22-540, book, 108 pages, by J.J. Tiemersma and N.A. Heeren, TOOL, out of print.

This is an introduction to the historical range of small waterpowered devices, including waterwheels, turbines, and other units. We prefer **Industrial Archaeology of Watermills and Waterpower** for the historical coverage.

Water Power for the Farm, Bulletin No. 197, MF 22-525, booklet, 42 pages, by O. Monson and A. Hill, Montana Agricultural Extension Service, 1941, $7.00 from Interlibrary Loan Service, Roland R. Renne Library, Montana State University, Bozeman, Montana 59717-0022, USA.

"Information given here is intended to be helpful in the proper selection and installation of small waterpower equipment. Directions and specifications are included for the construction of some types of dams and water controls which are practical for use with waterpower plants.' Discusses waterwheels and water turbines, how to estimate the power available in a stream, cost considerations, and methods of power transmission.

The water measurement section is inferior to **Low Cost Development of Small Water Power Sites** and the Popular Science article. But this booklet provides more than the others on electrical systems. There is brief information on switches and wiring, for people not familiar with electricity. A wiring chart gives sizes of wires needed for different transmission distances, voltages, and total capacity. However, it does refer to equipment that is out of date (32 volts) in the U.S.

Another useful chart shows power output at the wheel shaft and from a generator, given different heads and different waterwheels and turbines.

Low-Cost Development of Small Water Power Sites, MF 22-513, booklet, 43 pages, by H. Hamm, 1971 (reprinted 1975), $7.50 (overseas orders add $3.00 for surface mail, $5.00 for airmail), from VITA; also available in Spanish and French.

This important booklet is a guide to the desirability, selection, construction, and installation of a small waterpower plant. "The manual begins by describing in simple language the steps necessary to measure the head (the height of a body of water) and flow of the water supply, and gives data for computing the amount of power available. Next it describes the construction of a small dam and points out safety precautions necessary ... a discussion of turbines and water wheels .... Guidelines are given for making the right choice for a particular site .... The manual also describes in detail how to make a Michell (or Banki) turbine in a small machine shop with welding facilities, from usually available pipe and other stock material."

The booklet includes 32 drawings and sketches of different installations and pieces of equipment. The author recommends several companies that manufacture waterpower equipment, cautioning that "the hazards accompanying the manufacture of so delicate a machine by do-it-yourself methods and the difficulty of achieving high efficiency should warn the ambitious amateur to consider the obvious alternative of securing advice from a reliable manufacturer before attempting to build his own."

Your Own Water Power Plant, MF 22-510, article with drawings, 16 pages, by C. Basset in **Popular Science** magazine, 1947, reprinted in **Hydropower**.

This is a classic how-to article, written in simple language and covering much of what you need to know to build your own waterpower plant. Its usefulness is underlined by the fact that it has been reprinted so many times recently.

The article covers choice of location for a small dam, the measurement of flow and head with simple common tools, small dam construction, making a wooden flume and wooden overshot waterwheel, and fabricating a Pelton impulse wheel.

This article does not cover the final use of the power produced—neither electricity-generating equipment nor mechanical power are discussed.

Hints on the Development of Small Water-Power: Leffel Pamphlet "A" MF 22-509, leaflet, 8 pages, James Leffel and Company, Ohio, out of print.

This pamphlet was prepared for those who are thinking of building small waterpower plants on small streams to generate electricity. It is intended to give necessary information to people unfamiliar with the general rules and requirements of such developments. Explains the terms "fall" and "head," and how to measure the "head." Includes a simple table for measuring the quantity of water. Discusses the importance of ponds for water storage.

James Leffel and Co. have been manufacturing waterpower equipment for 115 years. The pamphlet is quite useful in itself, and does not require the reader to buy any of the company's equipment.

Hydropower, MF 22-510, book, 72 pages, edited by Andrew MacKillop out of print.

This was published to encourage the use of small-scale waterpower systems in Britain. Includes reprints of **Your Own Water Power Plant** and **Leffel Pamphlet "A"** (see reviews). One additional 6-page article on waterpower is included, plus articles on other unrelated subjects. Written with a humorous tone.

Young Mill-Wright and Miller's Guide, MF 22-528, book, 400 pages plus 28 plates (drawings), by Oliver Evans (watermill engineer and inventor),1850 (reprinted 1972), $32.00 from Ayer Co. Pubs., P.O. Box 958, Salem, New Hampshire 03079, USA.

A handbook written and used during the era when waterwheels were most common. This is a remarkable, classic book on the use of waterwheels to grind grain into flour and to operate equipment such as saws. The entire book is oriented toward practical applications. The major subjects include the relevant principles of mechanics and hydraulics, descriptions of the different kinds of wheels including tables with proportions and power, descriptions of gears and cogs along with the additional equipment needed for grinding grain into flour, and information for building mills including the wheels and all auxiliary equipment. You can also find short discussions of the strength and durability of teeth of wheels, the bearings and shafts, constructing cogwheels, and mills for hulling and cleaning rice.

"The stones are to be dressed with a few deep furrows, with but little draught, and picked full of large holes; they must be set more than the length of the grain apart. The hoop should be lined inside with strong sheet-iron, and this, if punched full of holes, will be thereby improved. The grain is to be kept under the stone as long as necessary. The principle by which the grains are hulled, is that of rubbing them against one another, between the stones with great force; by which means they hull one another without being much broken by the stones." (From description of "a mill for cleaning and hulling rice.")

The language used may well prove difficult at times for non-native English speakers; old forms are frequently used which may not appear in current two-language dictionaries. There are fewer drawings than we would like to see; they are grouped at the back instead of appearing with the corresponding text. On the other hand, this appears to be by far the most complete book still in print on large, powerful waterwheels.

Mill Drawings, MF 22-517, 30 large sheets, measurements and details, by W. Forman, 1974, The Society for the Protection of Ancient Buildings, England, out of print.

Each of these 30 sheets contains a set of perspective and scale drawings of a different old, large watermill installation. These are actual sites, and the drawings include lots of details of the wheels, machinery, and layout of each mill. Some of them are very unusual. There are overshot, undershot, and breast waterwheels shown. A possible source of ideas.

A Design Manual for Water Wheels, MF 22-501, booklet, 71 pages, by William Ovens, 1975, $7.25 from VITA; also available from ITDG and TOOL.

This booklet is a result of a Papua New Guinea University of Technology project involving the development of low-cost machinery (waterwheels) to provide small amounts of mechanical power in remote locations. The manual is "for the selection of proper sizes required to meet a specific need and to set out design features based on sound engineering principles" in easily understood language. Wooden overshot wheels were selected as "the most likely choice to give maximum power output per dollar cost, or per pound of machine, or per manhour of construction time." The booklet covers the general principles of bucket design, calculating power output, bearing design (use of wooden bearings recommended), shafts, some information on construction techniques, and waterpumping applications. A set of sample calculations for the design of a village waterwheel/pump combination is given. No specific plans are provided.

The slow speed of rotation of wooden waterwheels (5 to 30 rpm) "is advantageous when the wheel is utilized for driving certain types of machinery already in use and currently powered by hand. Coffee hullers and rice hullers are two which require only fractional horsepower, low-speed input. Water pumping can be accomplished at virtually any speed .... A usable water wheel can be built almost anywhere that a stream will allow, with the crudest of tools, and elementary carpentry skills"

This leaflet's major weakness is the lack of illustrations. There are a variety of graphs, but only 7 drawings—only two of these have to do with the design of the wheel itself. There are 4 good drawings of mechanisms to convert the rotational motion of the wheel into the up and down stroke that a piston pump requires. The piston pump design provided is questionable—it must be cut open for inspection or repair.

Despite the lack of illustrations, we highly recommend this booklet to anyone considering the construction of overshot waterwheels. (See also **Oil Soaked Wooden Bearings**.)

Overshot and Current Water Wheels, Bulletin 398, MF 22-520, booklet, 30 pages, by O. Monson and A. Hill, reprinted September 1975, photocopies $7.00 from Interlibrary Loan Service, Roland R. Renne Library, Montana State University, Bozeman, Montana 59717-0022, USA.

This 1920s booklet is a valuable supplement to others, such as the **Design Manual for Water Wheels and Low Cost Development of Small Water Power Sites**. It gives details of bucket construction and mounting, hubs, and bracing for wide wheels. Useful hints are provided on bearings, wheel mountings, and assembly and balancing of the wheel. A chart compares steel shaft diameters to wooden shaft diameters for equal strength in twisting (shear). There is some discussion of the special problems presented by current (undershot) wheels.

This does not include the design formulas needed to design your own waterwheel if you know the available flow and head (height).

Watermills with Horizontal Wheels, MF 22-526, booklet, 22 pages, by Paul Wilson, 1960, The Society for the Protection of Ancient Buildings, London, out of print.

This is a survey of the vertical-axis, small "horizontal stone" watermills widely used around the world for 1500 to 2000 years, and still in use today in isolated areas of countries like Nepal. A number of different installations around the world and six different mill wheel designs are shown. These machines are "not as efficient as an overshot or breast wheel, but they have the virtue of simplicity due to the absence of gearing," and they are very cheap to build. (Another book notes that this type of mill is able to produce 40 to 50 pounds of cornmeal per hour; Nepalese watermills grind about 30-35 pounds per hour.)

Most of these watermills had a wooden trough bringing fast-moving water to strike the blades of the wheel, with a head of 4-10 feet. Two types of pressurized systems also evolved, one using wooden channels with nozzles, and the other using stone towers with nozzles. "The Aruba Penstock (water tower) was introduced (in Israel), giving much greater efficiency and enabling power to be obtained from quite small flows of water using heads up to 25 or even 30 feet."

On Watermills in Central Crete, MF 22-519, booklet, 8 pages, by N. Calvert, 1973, 70 pence in sterling including postage (prepayment only) from The Society for the Protection of Ancient Buildings, 37, Spital Square, London E1 6DY, England.

This is a look at two kinds of waterwheels in Crete. The most interesting one is a traditional vertical axis watermill, that has a stone tower and a pressurized jet with a deflector (almost like a modern high-speed Pelton wheel). "The constructional materials are of the simplest and most local description. With one important exception: (the millstone) stones are small and unworked, timber is of small dimensions ... clay is used and a very little iron. An effective and sweetly running machine is built from what is literally little more than a supply of sticks and stones."

The author notes that the basic layout of these wheels is so technically sound that modern improvements (in nozzle and blade design) could improve efficiency by only about 20%.

New Himalayan Water Wheels, MF 22-538, booklet, 84 pages, by Andreas Bachmann and A.M. Nakarmi, 1983, UNICEF/Nepal, out of print.

Nepal is probably the leading country today in the installation of improved water-driven wheels and turbines for mechanical power. The many photos in this booklet illustrate details of traditional Nepalese watermills and a variety of newer alternatives, both well-established and experimental. The text summarizes the experimental work to late 1983.

Multi-Purpose Power Unit with Horizontal Water Turbine: Basic Information, MF 22-518, booklet, 60 pages, by A.M. Nakarmi and Andreas Bachmann, 1983, UNICEF/Nepal, out of print.

An estimated 30,000 ghatta, traditional water-powered mills, are in use in Nepal. This book describes the Multi-Purpose Power Unit (MPPU), a modular design mill which is based upon the traditional ghatta but is more efficient and can be used to power other machines such as a rice huller, oil expeller, or small dynamo for generation of electricity. Although the MPPU would not typically be constructed entirely on site and the MPPU is more expensive than a ghatta, it is produced in the country, and can be installed and operated under the same conditions as a ghatta. Its simple design makes local maintenance possible. Detailed plans for construction are not presented, but many diagrams and photographs are included so that the basic design concepts for the MPPU are easily understood.

Multi-Purpose Power Unit with Horizontal Water Turbine: Operation and Maintenance Manual, MF 22-536, booklet, 36 pages, by A.M. Nakarmi and Andreas Bachmann, 1984, UNICEF/Nepal, out of print.

This second volume on the Multi-Purpose Power Unit is an operator's manual for the turbine and the milling equipment (small rice huller and oil expeller) commonly used with it in Nepal. Included is a trouble-shooting chart to help identify and solve mechanical problems.

Nepal: Private Sector Approach to Implementing Micro Hydropower Schemes, MF 22-537, booklet, 26 pages, by Allen Inversin, 1982, $4.00 surface mail from Small Decentralized Hydropower Program, International Programs Division, National Rural Electric Cooperative Association, 1800 Massachusetts Avenue N.W., Washington DC. 20036, USA.

Possibly the most successful developing country experience with low-cost steel water turbines (outside of The People's Republic of China) has been in Nepal. Blades for the small turbines, which cost only a fraction of the cost of similar units in industrialized countries, are cut from steel water pipe and welded in place. Production is done in workshops in Kathmandu and Butwal, and the units are trucked and then hand-carried into the inaccessible middle hills. The turbines are sold to mill owners, who use them to drive grain grinders, paddy hullers, and oil presses.

This insightful case study describes the typical mill layout and the organizational structures that have been set up to work with customers do site surveys and install the units.

Small Water Turbine, book, 123 pages, by H. Scheurer, R. Metzler, B. Yoder, 1980, from German Appropriate Technology Exchange, Postfach 5180, D-6236 Eschborn 1, Federal Republic of Germany.

This book covers much of the same material as **Nepal: Private Sector Approach**. In addition, background information on the history of the Butwal water turbine program indicates the problems faced and why particular components and fabrication techniques were finally chosen. Technical drawings are provided.

Micro-Hydropower Schemes in Pakistan, MF 22-532, booklet, 38 pages, by Allen Inversin, December 1981, $4.00 surface mail from Small Decentralized Hydropower Program, International Programs Division, National Rural Electric Cooperative Association, 1800 Massachusetts Avenue N.W., Washington D.C. 20036, USA.

Village electrification is being done in Pakistan using a variety of design simplifications, low-cost locally made turbines, Chinese generators, and village materials and labor. This booklet describes 25 ATDO-sponsored installations in the range of 5-15 kw that attracted great interest and enthusiasm in the villages. The crossflow turbines have rudimentary governing systems. Penstock for water delivery from the canal to the turbine is made of wood or oil drums if the head is less than 6 meters. Costs were US $250-400/kw (1978 dollars).

Local Experience with Micro-Hydro Technology, SKAT Publication No. 11, Vol. 1, MF 22-512, book, 176 pages, by U. Meier, 1981, Swiss Francs 32.00 from SKAT.

A comprehensive examination of the potential for hydropower, particularly micro-hydro (installations producing less than 100 kw), in meeting the energy needs of developing countries. Considerations of technology choice emphasize in-country production and appropriate application of energy, relaxed standards for local manufacture of components, cooperative ownership, and on-the-job training to encourage adoption of this promising energy alternative. Includes ease studies, some technical data, bibliography, and a list of institutions and organizations involved in hydropower development.

Recommended.

Design of Cross-Flow Turbine BYS/T1, Construction Manual, Drawings Set, MF 22-502, booklet, 113 pages, by U. Meier, 1982, Swiss Francs 30.00 from SKAT.

Engineering drawings and parts lists for construction of the BYS cross-flow turbine developed in Nepal, including housing and hand-operated flow control mechanisms. Steel plate and pipe are the construction materials, and a well-equipped metalworking shop is required.

Design of Cross-Flow Turbine BYS/T3, Construction Manual, Drawings Set, MF 22-503, drawings, by U. Meier, 1982, photocopy, Swiss Francs 30.00 from SKAT.

Similar to **Cross-Flow Turbine BYS/T1**. Produces 10 kw to 20 kw with a 5-70 meter head.

The Banki Water Turbine, MF 22-500, booklet, 27 pages, by Mockmore and Merryfield of the Engineering Experiment Station, Oregon State University, 1949, $2.00 in U.S., $4.00 foreign, from Engineering Experiment Station, Oregon State University, Corvallis, Oregon 97331, USA.

This booklet has lots of somewhat sophisticated mathematics and diagrams that explain the theory behind the Banki turbine, filling up most of the text. Oregon State University built an experimental version that worked quite well—a brief discussion of that unit is included.

Small Michell (Banki) Turbine: A Construction Manual, MF 22-524, booklet, 56 pages, by W.R. Breslin, 1979, $9.50 from VITA; also available from TOOL.

This is basically a reprint of the VITA booklet, **Low Cost Development of Small Water Power Sites** (see review), with an expanded (15 page) section on construction of a Banki turbine.

Specifications are given for only one turbine diameter (30 cm), but turbine width can be varied to accommodate different volumes of water. The plans require 10 cm diameter steel water pipe for the turbine blades, and steel plate for the sides and nozzle. Welding, cutting and grinding tools are needed. The turbine can be used for direct drive of agricultural equipment or for producing electricity. (You will have to look elsewhere for the information to help you set up a proper electrical installation.)

A site with a head (total height water will fall) of 25 feet (7.6 m) and a flow of water of 2.8 cubic feet per second (81 liters per second) would produce about 6.3 hp (4.8 kw) of power at the turbine. Transmission losses or generator losses can be expected to cut this by 1/3 to l/2.

Manual for the Design of a Simple Mechanical Water-Hydraulic Speed Governor, MF 22-514, booklet, 40 pages, by U. Meier, 1980, Swiss Center for Appropriate Technology, out of print.

This manual describes the mechanical speed governing system developed by Balaju Yantra Shala (BYS) in Nepal to control their cross-flow turbine. Schematic drawings help explain the operation of the unit, and detailed drawings provide information for construction of the key load-regulating valve.

"It is mostly cost that has stood in the way of speedy and large-scale development of small hydropower potentials (in developing countries). Imported and sophisticated equipment becomes costlier and costlier and is in most cases not economically feasible. This applies mostly to hydraulic equipment such as water turbines, accessories and governing devices. The case is different for alternators and switch gear which are produced in great number in industrialized countries and are therefore relatively cheap."

"Experience in Nepal shows that it is possible to reduce costs of hydroelectricity generation projects vastly by minimizing civil engineering and structural works and by producing hydraulic equipment in local workshops with simple designs and technology."

"Nonavailability of a simple mechanical governor has long been a major obstacle in implementing small hydro projects with acceptable standards of safety. The Swiss Association for Technical Assistance, Helvetas, in Zurich has sponsored a project to develop a simple governor that would be sufficiently accurate and reliable and could be manufactured by local workshops in Nepal .... A prototype was built and tested in early 1979. The governor was designed for operating the gate of a crossflow (Banki) turbine, but may in fact be utilized on the flow regulator of any turbine.... This construction manual may enable other organizations and individuals to adapt this governor to their own needs and improve it further as a contribution to the design of simple but reliable hydraulic equipment for small electricity generation units."

The Dhading Micro-Hydropower Plant: 30kWe, MF 22-506, booklet, 29 pages, by U. Meier, 1983, SKAT, out of print.

This paper describes a micro-hydropower plant using a BYS MWH/P-governor and complements **Manual for the Design of a Simple Mechanical Water-Hydraulic Speed Governor**. Diagrams and photographs include a hydraulic profile of the turbine, a schematic of governor hydraulics, a proposed hydraulic damping arrangement, and photographs of equipment installed. General information presented includes technical specifications, plant performance and operation, plant safety, and a summary of the data collected

The Segner Turbine: A Low-Cost Solution for Harnessing Water Power on a Very Small Scale, MF 22-522, booklet, 13 pages, by U. Meier, M. Eisenring, and A. Arter, 1983, $2.00 or Swiss Francs 4.00 from SKAT.

This very simple turbine is currently being produced in Nepal for US $670 (1983 prices). The history and operation of the turbine are presented along with basic design details. The authors find that for Nepal, the Segner turbine is only economical for certain functions such as oil extraction and rice hulling. The traditional ghatta was found to be more economical for milling of grains, and the Segner turbine cannot be scaled up sufficiently to replace the standard turbine for applications requiring a high-power output.

Small Hydropower for Asian Rural Development, MF 22-542, book, 353 pages edited by Colin Elliott, 1981, $27.50 to developing countries, $35.00 to developed countries, from Regional Energy Resources Information Center, Asian Institute of Technology, P.O. Box 2754, Bangkok 10501, Thailand.

This well-matched set of conference papers provides a good introduction to the technical, environmental, and financial aspects of micro and mini (10 kw to one MW capacity) hydroelectric plant development. More extensive than **Small Hydroelectric Plants**, this volume also includes some case studies from Asia, most of the text would be relevant in any developing country. For readers interested in rural electrification using hydropower, this is a good place to start.

Small Hydroelectric Powerplants, MF 22-539, book, 333 pages, 1980, Small Decentralized Hydropower Program, National Rural Electric Cooperative Association, out of print.

The English and Spanish text side by side in this volume cover some of the same ground as **Small Hydropower for Asian Rural Development**, but with case studies from Latin America. This too is a compendium of conference papers. Typical installations are described. A glossary is included.

Microhydropower Handbook, Volume l, MF 22-533, and Volume II, MF 22-534 books, 920 pages, by EG&G Idaho for the U.S. Dept. of Energy, January 1983, order no. DE83-006697 (Vol. I) and order no. DE83-006698 (Vol. 2), paper copies of each volume $45.00 domestic, $90.00 foreign, from NTIS.

Intended as a guide for individuals attempting to develop small hydroelectric power sites in the U.S., the handbook "assumes that the reader has little working knowledge of hydropower or the engineering concepts behind the use of hydropower." The authors have attempted "to provide a mechanically proficient lay person with sufficient information to evaluate micro hydropower site potential, lay out a site, select and install equipment, and finally, operate and maintain the complete system. The actual construction details of the site are not included; rather, pointers are given as to what help he should expect from a construction contractor, and general guidelines on construction details are provided. In addition, information about obtaining financing and permits is provided. To help offset the cost, the person performing the work, referred to as the 'developer', is encouraged to do as much of the work as possible"

This is probably a necessary book for people in the U.S. who wish to develop a micro hydropower site and sell the power to the utilities. Where to get government stream flow data and the necessary permits are among the topics discussed that are essential in the U.S. but irrelevant elsewhere. The two volumes are lengthy and expensive, but probably represent the most accessible in-depth presentation of the technical considerations for anyone without a previous background in the field who is seriously interested in developing a site (e.g., of 100kw potential).

For projects based in the South, the **Microhydropower Sourcebook** by Inversin will be much more helpful than this book, as it concentrates on the different problems and opportunities found in these places.

Mini Hydro Power Stations (A Manual for Decision Makers), MF 22-535, book, 163 pages, UNIDO, 1981, document #UNIDO/IS.225, available from UNIDO.

This manual provides project managers with an overview of the steps and considerations involved in the establishment of medium-scale ("mini") hydroelectric units, from prefeasibility studies to operation and maintenance. Common problems are noted, as are advantages and disadvantages of different materials and operational structures. For the intended audience, this should prove to be a useful reference. The reproduction quality of the text (particularly the charts which are often too small to read) is below average; this is likely to be corrected when this material is reissued as part of UNIDO's Development and Transfer of Technology series.

Directory of Manufacturers of Small Hydropower Equipment, MF 22-530, booklet, 71 pages, by Allen Inversin, 1984, Small Decentralized Hydropower Program, National Rural Electric Cooperative Association, Washington, D.C., out of print

A good summary of cost saving strategies for small hydropower installations (1-1000 kw range) starts off this volume. This is followed by a description of manufacturers worldwide, some of them quite small, and some of them located in developing countries. This information should be quite helpful in obtaining price quotes.

A "method for reducing the cost of a hydropower installation which is gaining popularity is to use pumps in reverse as turbines .... Because they are often mass produced by numerous manufacturers, costs are reduced. Since they are standardized and available off-the-shelf, delivery times are minimized .... One major difference between pumps and turbines is that the former are designed to operate under a single set of conditions. There is no efficient way of controlling flow through a pump .... (However,) by using at least two pumps, preferably of different capacities, it is possible to harness a significant portion of the energy available in varying flows ... the relatively low cost of pumps still permits the economical use of multiple units for power generation."

Cost Reduction Considerations in Small Hydropower Equipment, MF 22-529, paper, 12 pages, by D. Minott and R. Delisser, 1983, publication no. ID/ WG.403/21, UNIDO, out of print.

A useful summary of alternative materials for penstock construction is the unique feature of this brief paper. PVC, wood stave, fiberglass-reinforced polyester and asbestos cement penstocks are discussed.

"PVC pipes can be supplied to withstand heads of over 150 meters so long as an appropriate method of making joints is utilized to guarantee proper sealing. Although in many developing countries it is not possible to obtain PVC pipes in excess of 5 meters long with more than a 12 inch internal diameter, it is possible and even desirable where required to run two pipes in parallel in order to approximate a larger diameter penstock. But PVC has a low-impact resistance and becomes fragile from prolonged exposure to sunlight ultraviolet radiation, so it is recommended that such penstocks be installed underground to increase the life of the installation."

Harnessing Water Power for Home Energy, MF 22-507, book, 112 pages, by Dermot McGuigan, 1978, Garden Way Publishing, Schoolhouse Road, Pownal, Vermont 05261, USA; indefinitely out of stock.

This is a good book for someone who wants to learn about the different small-scale water turbines that can be used to generate electricity. The Pelton wheel, Turgo impulse wheel, Banki (Ossberger) cross-flow turbine, and Francis turbine are shown in a total of 6 actual installations in England and the United States. Costs are provided for many of these examples. Only the Pelton wheel and Banki turbine are really suitable for construction in a small workshop. Manufacturers of turbines and whole systems are listed from around the world.

Useful notes are included on alternators, transmission drives, dams, and the electronic governor (a device which switches part of the electric current away from the main line—to heat water, for example—when the electric demand falls; this eliminates the need for an expensive mechanical governor which regulates the amount of water flowing through the turbine).

There are many drawings and photos, but these are poorly explained. Electrical circuitry is not shown, and mechanical governors are not explained. Waterwheels are only briefly covered in a few pages. The examples are all single homes in rich countries, using large amounts of electricity. The language is relatively easy to understand, although a number of waterpower engineering terms are used without explanation.

You will not be able to build anything from the information contained in this book, but you can get a better idea of what would be required to install a small waterpowered electric system, on a useful scale for village electrification.

Micro Pelton Turbines, Harnessing Water Power on a Small Scale Volume 9, MF 22-543, book, 84 pages, by Markus Eisenring, 1991, GATE/ SKAT, available from SKAT.

A small Pelton turbine can be a good choice of water turbine for circumstances in which a modest amount of water is available at a high head. The Pelton turbine can be less than a foot (30 cm) in diameter, rotates at a high rpm, and is generally used to produce electricity. This manual provides a good introduction to the design and production of Pelton wheels in developing countries. The Pelton wheel is the second easiest turbine to make, after the more widely applicable cross-flow turbine (covered elsewhere). Little coverage is given to the actual use of the power produced or the governing equipment necessary to control the speed and power output. Four examples of small installations in Switzerland are provided.

A Pelton Micro-Hydro Prototype Design, MF 22-521, report, 41 pages, by Allen Inversin, 1980, ATDI, K6.75 (plus postage if outside Lae) from Liklik Buk Information Center, ATDI UNITECH, P.M.B. 793, Lae, Papua New Guinea.

"Is it possible that introducing electricity into rural villages could be one factor towards rejuvenating life in these villages? Can a technically and socially appropriate system with active villager participation in the planning, installation, management, and evolution of their own scheme have beneficial effects?"

"This report describes work to date on a modular design for a Pelton micro-hydro generating set with an electrical output up to ... 5 kVA and with a 'typical' installation cost of about K300/kVA ($400/kw) including penstock costs .... This is less expensive than diesel generating sets, and, when recurring costs are included, less costly than both diesel and petrol. Also covered briefly are ideas on governing bucket design and prototype performance, and cost/kw of PVC penstock pipe for different site configurations and pipe diameters."

Pelton wheels requiring a head of 50 feet or more were chosen, due to the mountainous terrain and small water flow required by these units. General design guidelines were to develop a low-cost but rugged design, which could be locally fabricated with a minimum of special skills, and which could be easily installed with little site preparation.

Notable design simplifications include: 1) a low-cost easily-made iron pipe cover for the main shaft, which prevents water from entering the bearings; 2) use of holes in steel plate to replace nozzles; 3) pulley substitution to adjust for actual head at the site; 4) bolted assembly. The author also discusses a variety of ways to eliminate the need for expensive mechanical flow governing systems.

This well-illustrated report is a valuable description of the state of the art of low-cost micro-hydroelectric systems using Pelton wheels. It incorporates ideas and suggestions based on pioneering work in Colombia at Universidad de los Andes. The technology is widely relevant in mountainous areas of developing countries.

Design of Small Water Turbines for Farms and Small Communities, MF 22-505, book (including working drawings for a selected water turbine), 163 pages, by Mohammed Durali, 1976, Technology Adaptation Program, Massachusetts Institute of Technology, out of print.

This is a report of a project "to study alternative water turbines producing 5 kw electric power from an available hydraulic head of 10 m and sufficient amount of flow, and to recommend one for manufacture," for use on Colombian coffee farms.

Much of the book presents the sophisticated mathematics and physics of turbine design for optimum performance. This requires some technical training to comprehend. The relationships between the various elements in the design are given in equations, allowing choice for simplicity in particular elements.

The design criteria included: simplicity of operation and maintenance (the machine is intended for use by farmers with little technical knowledge); and lower cost of electric power over the life of the machine when compared with transmitted power from the main electric grid. Choice of turbine would be determined in part by which of two production alternatives was selected: 1) use of a simple workshop capable of welding, drilling, and cutting steel parts (local farming area production); or 2) use of more sophisticated production methods like casting and molding with some plastic parts (industrial production at a centralized level).

"The work consisted of the preliminary design of different types of water turbine which could be used for this application. Then one was selected and designed completely. A complete set of working drawings was produced for the selected type."

"Four different types of water turbine were studied: a cross-flow (Banki); two types of axial-flow turbines; and a radial-flow turbine. Each one has some advantages and some disadvantages (explained in the text). One of the axial-flow turbines ... was chosen for detailed design as presenting the optimum combination of simplicity and efficiency."

The materials range from riveted pieces of thin-wall steel tubing for the blades, wooden bearings, and bicycle sprocket/chain drive (Banki turbine) to molded, extruded, or cast plastic blades (axial-flow turbine).

"A big portion of the price of each of the units is the generator cost. The rest of the construction cost seems likely to be similar for all units for small-scale production. For large-scale production the cross-flow will be much more costly than the axial-flow types. This is because the material cost for the axial-flow machines is small, but initial investments for molds and dyes are required."

Design of Small Water Storage and Erosion Control Dams, MF 22504, booklet, 79 pages, by A.D. Wood and E.V. Richardson, 1975, publication PN-AAB-118, $12.49 from AID Document and Information Handling Facility, 7222 47th Street, Suite 102, Chevy Chase, Maryland 20815, USA.

Covers design criteria and construction methods (mechanical and manual) for small earth and rock-filled dams. Includes discussion of several types of ponds, foundation conditions, and water uses, with special attention to outlet spillways. An appendix covers seepage and its influence upon design. The text is somewhat dense and a bit dry in style, but contains much useful information.

Small Earth Dams, Publication No. 2867, MF 22-523, booklet, 23 pages, by Lloyd Brown, 1965, U.S. Dept. of Agriculture, out of print 1980, contact an appropriate technology information center for a photocopy.

This introductory booklet has practical suggestions for those who want to build small dams to make ponds for irrigation or watering animals. Although the focus is on U.S. climate and methods, the booklet could be useful as a starting point for building low-head dams for micro-hydroelectric systems anywhere. The information is only for use in small (6 feet and under) dams and those dams that back up a limited amount of water. There are suggestions for selecting a site, a few hints on construction, and maintenance and management practices for the reservoir and spillway (water outlet).

Micro-Hydro: Civil Engineering Aspects, MF 22-516, paper, 11 pages, by D. Mansell, G. Atkins and S. Kiek, free from Dr. Don Mansell, Appropriate Technology Section, Faculty of Engineering, University of Melbourne, Parkville, Australia 3052.

This paper identifies "some of the aspects of small hydro-electric schemes which are of particular concern to the civil engineer, and provides some guidance to non-engineers who wish to build such power sources .... (Includes) facts, problems and ideas which may be of interest to a person wishing to investigate the feasibility of a small scheme."

Discusses calculations for low flows, flumes and channels (earth, timber, concrete, and steel), and soil problems in small earth dams. The perspective is that of using local materials for small waterpower schemes in isolated rural areas.

"It is possible to build small dams with reasonable certainty of success with the use of a little simple technology. Such dams should not exceed 5 meters in height."

ADDITIONAL REFERENCES ON WATER POWER

Renewable Energy Resources and Rural Applications in the Developing World describes the evolution of the waterwheel and water turbine in rural industry in Europe, the United States, and present-day China; see ENERGY: GENERAL.

The Power Guide contains information on commercially available water turbines and a stream flow water pump; see ENERGY: GENERAL.

Hydraulic ram pumps are the subject of several publications reviewed in WATER SUPPLY.

More Other Homes and Garbage; see GENERAL REFERENCE.

Teknologi Kampungan includes several traditional Indonesian waterwheels; see GENERAL REFERENCE.