Micro-Hydro Power: Reviewing an Old Concept

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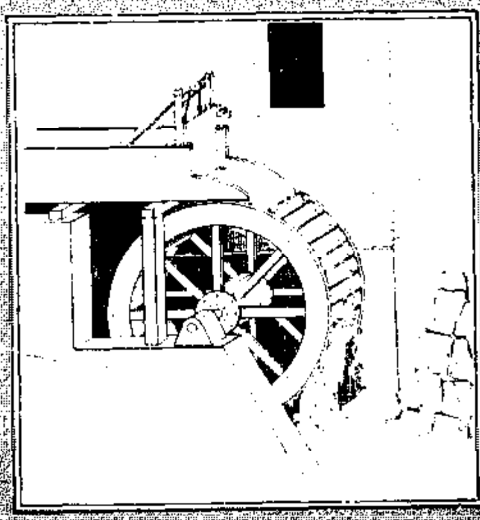

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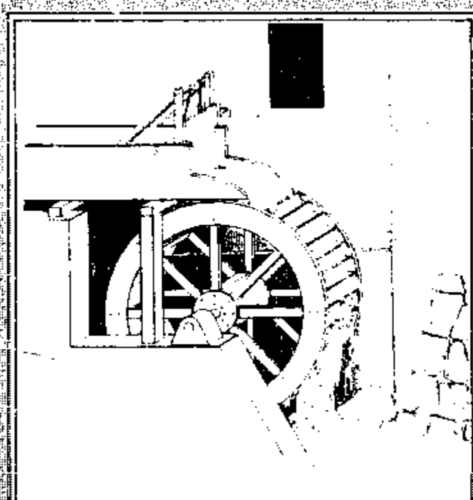

REVIEWING AN OLD CONCEPT

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by
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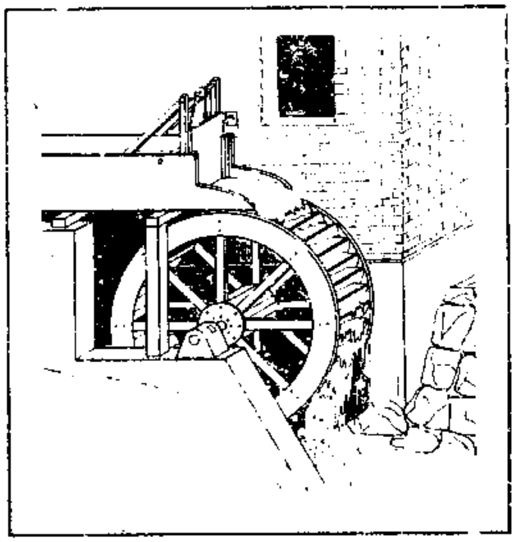

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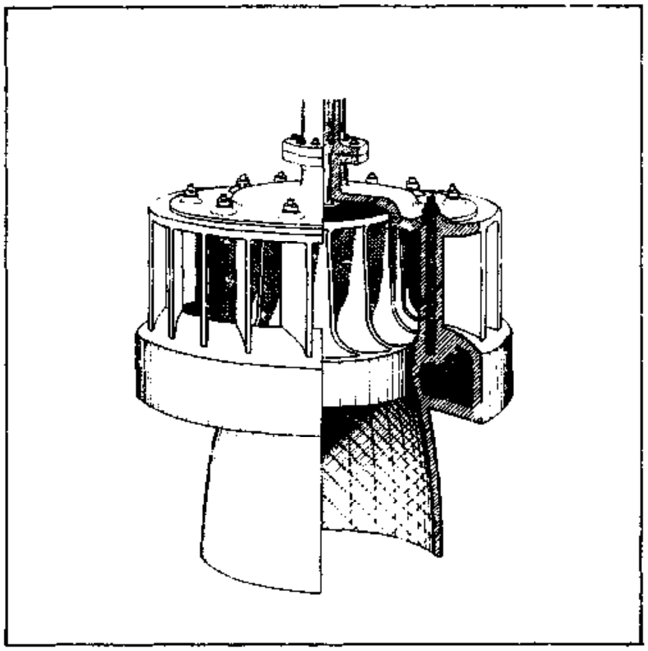


Introduction

Today there is a great deal of public interest in renewable energy sources such as solar, wind, tides, flowing water and biomass for producing power for home, shop and farm appliances. Many of the technologies for converting these renewable sources into useful power have been with us for centuries and are now once again receiving widespread attention. The generation of power from flowing and falling water is no exception. In fact, it is one of the world's oldest and most common energy technologies. But right now hydro power means big dams and large-scale generation facilities to most people in North America. On a world-wide basis, however, small-scale, environmentally benign, mechanical and electrical hydro power systems are much more common. These are the systems for individual homes, farm and shop use and generally have power outputs less than 100 kilowatts. For convenience in terminology, this scale of hydro power is referred to as **micro-hydro.**

This information package has been prepared to respond to an increasing number of requests for information on micro-hydro systems. It is designed to introduce the reader to all aspects of micro-hydro, from first consideration of the idea through to production of power. We have attempted to include as much information as necessary to get you started in the process and to assist you at each step along the way. We are stressing your involvement in the development of your hydro power system, so a major part of the contents of this brochure only serves to give you guidelines. They do not, and cannot, provide detailed descriptions of every stage of the process, since micro-hydro development is very site specific. Each town, municipality and state has differing regulations, and your personal motivation and economic situation are probably very different from the next reader.

One of the particular problems we are addressing is where you can go to get adequate information that will meet your needs -- whether you want to do it yourself or get someone else to do it for you. The Extension Service of the Department of Agriculture used to be the place to go for this information back in the 1920's. They thought of it as part of their job to help rural dwellers with their energy problems. But R.E.A. took care of that, putting most farm and home sites on a regional and eventually national electricity grid. That need, though, has come around again. Now a lot of the older information is outdated. Newer equipment has come on line; different manufacturers and suppliers exist. Nevertheless, today if you go to any major library, including technical and engineering libraries, very likely the best resources in the field are still going to be books published prior to the 1930's. That is because of the lack of interest in micro-scale hydro systems in North America since that time. Some up-to-date written information does exist, but for the most part it is fragmented. There are also a number of people around the world who know a lot about small and micro-hydro systems, but it is difficult for the average person to find out who these people are and where they can be contacted. This information package contains a resource directory, which is an attempt to put you in contact with the literature, plans, people and companies appropriate to your needs.

Decision Tree

Are you interested in using micro-scale hydro power to generate electrical or mechanical power? To cut your energy bills? To become more, or completely, independent of the local utility? To become more responsible for and responsive to the technologies you use? Whatever the reasons, you have probably already given it some serious thought, but may not know how to go about determining the feasibility of using hydro power, or who manufactures and sells the equipment, or if a permit to develop it is necessary, and where and from whom it can be obtained. What are the problems found along the way and where do you go for help when a problem is encountered?

We have attempted, in this section, to evolve a sort of "decision tree" to help you find out if you are able to, or want to, and how to, develop your site for micro-scale hydro power. We have tried to indicate points of access to and exit from this decision tree. And we have tried to indicate at what point and how these decisions are made.

As you follow through this section, each step will lead you farther along the way, or eliminate you from the process. However, we are interested in leading you to eventual success, so don't get discouraged if the going gets rough. Once you become involved you will realize that this is not like operating a car; you don't simply turn the key on. You're in a rediscovered field and you are a pioneer in its development. So although things may be in a bit of disarray, and you feel yourself getting bogged down in a water rights issue or in licensing problems, remember that in most situations with the right attitude you can reduce or eliminate the red tape.

There are several avenues to final success and all of them depend on you and the degree of your involvement in the process. You may follow every step through on the do-it-yourself model, including building your own equipment and hand-holding every official through permit formalities, or you may hire an attorney or consultant and pay to have it installed. Or, you may try numerous combinations of these two.

What we want to do here is to give you enough information so that you are able to make that first decision as to whether it is worthwhile pursuing the subject any further. And if it is worthwhile, the following pages provide you with guidelines for each step along the way.

We will put cautions and stop-flags where we think the limits are, and we'll indicate to you how rough the estimates may be. But one thing we want to stress is: If it looks as though there is any possibility at all, go on to the next step!

If you come out of this process still with us, then go talk to the equipment suppliers, buy the equipment, or make it, and install it!

STEP 1.

Obtain Access To Land With Running Water.

The running water may be a spring or a permanent stream (or intermittent if seasonal energy use is considered). If you own the land, go on to Step 2. If you are thinking of purchasing the land, or leasing it for long term, then go to Steps 2 through 4 to determine if it is worth your while to obtain the land.

STEP 2.

Determine If The Resource Meets Your Lifestyle Energy Requirements.

If there is not enough energy available in your stream to come close to what you feel are your needs, then there is not much sense in going any further. On the other hand, your water resource may contain an excessive amount of developable power and you may only want to use a part of it. In order to determine the potential power you have available in the stream, you will have to quantify the head and flow rate.

To determine the particular head and flow rate of your stream, turn to the section, *Determining the Hydro Potential of Your Site*, and pay special attention to the minimum flow considerations that are indicated. In order to find the power output potential from a typical hydro system installed in your stream, go to the nomograph on Page 15 with your flow rate and head measurements. You now have an idea of how much power you can get from your water resource.

Next, you need to determine how much power you require. If you are considering mechanical shaft power as your end use, e.g., for sawing, grinding, or whatever, then you need to know the power requirements of your machinery. If you want to use the energy available in the water for generating electrical power for domestic, shop or farm consumption, then you have to determine your electrical power needs. The best way to do this is to look at your current electricity bills and get an idea of the number of kilowatt hours you are using per month. Remember, if you are using electrical resistance heating, your bills will indicate a significantly higher electricity consumption during the winter months than during the summer. Another way to determine your electrical power needs is to turn to the table of *Typical Household Appliance Loads* on Page 14. This is a table of estimated average monthly power consumptions for appliances listed. Now compare your power needs with what is available from your water resource. If your monthly requirements are greater than the hydroelectric system will generate in a month, see where you can reduce consumption to try to match the available power. If your output is greater than the demand, you may have surplus power for other end uses such as space heating, operating a small electric kiln, selling to the utility, etc.

It is important to note that there is head and a flow rate below which there is currently no economic advantage of trying to obtain electrical power. These minimum heads and flow rates are difficult to specify because combinations of high values of one with low values of the others can give some useful power. For practical purposes in micro-scale hydroelectric systems, any head less than 10 feet is probably going to be uneconomical to develop. Similarly, 10 gallons per minute can be considered the lower limit to the flow rate. However, 10 gallons per minute at 10 feet of head is not going to give any usable electrical power. The following examples will indicate some minimum energy situations:

* A flow rate of 10 gallons per minute at 100 feet of head will give about 100 watts of useful power — enough to light a 100-watt light bulb continuously.

* A flow rate of 100 gallons per minute at 10 feet of head will also deliver about 100 watts of useful power.

STEP 3.

Determine If You Can Use The Resource.

Do you have a right to use the water or does that right reside elsewhere? Remember, in many states and particularly in the East, water rights do not necessarily transfer with land title. You will have to investigate this before you proceed any further.

Next, if there is a dam nearby or on your property, can you use it (e.g., buy or lease it)? Can you get a right-of-way for needed pipeline across adjacent properties? Can you get building permits if they are required, such as for a small powerhouse, dam or diversion?

Can you obtain the necessary licenses and permits for the installation (see the section on *Regulatory Conflicts*)? There are numerous licensing and permitting procedures you may have to go through. A lot depends on which state you are located in, whether or not the water rises and falls on your land, or just passes through, whether it comes from, goes to, or is in National Forest or Indian Tribal lands.

The water use permit process can be long and drawn out, so just investigate the feasibility at this point. If it looks at all possible, then go on to Step 4.

STEP 4.

Calculate The Costs Of The System.

Determine who the equipment suppliers are for your type of water resource and find out the costs of their equipment. Most equipment suppliers will be able to give you a rough estimate if you can supply them with the following information:

* Usable flow rate

* Length of pipe required from take-off to generator location, or location of dam with respect to generator location.

* Power demand -- quantity, and what used for.

* Whether you want AC or DC and what you want to do with any surplus power.

Include the costs of piping, dam repair or construction (if needed), laying the pipe, electrical set-up and constructing a small powerhouse to enclose the turbine, generator and electrics.

There are peripheral advantages to a hydro system. These include using the water for fire suppression, domestic water supply and irrigation. Can the inclusion of any or all of these offset other costs you currently have or expect to have? How do these affect the cost figure associated with the hydro system?

The next question that arises is: Are the above costs reasonable?

This question can only be answered by knowing your own reasons for getting involved with micro-hydro. Your non-economic reasons (e.g., environmental, energy independence) may outweigh any other considerations, but if you are like most of us, economics helps play a deciding role. To determine if you can afford the money outlay to put in a hydro system, you will have to look at the cost of alternatives, *Step 5*, and if an how the system can be financed, *Step 6*.

STEP 5.

The Cost of Alternatives To Micro-Hydro Systems.

Are you currently connected to the utility lines? How much are you paying for your electricity and would it be advantageous, economically, for you to disconnect and supply all your own power? You can determine the economic advantage to you, if any, by doing a calculation similar to that in the section on *Economics*.

If your site is isolated and the nearest utility lines are a mile or more away, you might find that the cost of installing a small hydro power system is very competitive with the cost of line extension. On the other hand, if you must use some commercial power, continuously or seasonally, in some cases the so-called "minimum rate charge" may eliminate a significant cost saving even if you do install your own micro-hydro system. It is wise to consider all these things.

STEP 6.

Methods Of Financing A Micro-Hydro System.

The capital costs associated with micro-hydro power systems are somewhat high. Typically they can run between $750 and $1500 per kilowatt of installed capacity. Some imported units can cost up to $2000 per kilowatt. Your method of financing the project is going to determine what you will actually pay per kilowatt hour of power used. The section on *Economics* will help you in making this calculation.

You can keep the cost down by doing a lot of the work yourself. You can build and install some of the needed components (all of them if you are so inclined and have the time). However, be forewarned — if you do most of it yourself, such things as building the various components, this might close off the traditional sources of financing. Loans are made on the basis of guaranteed collateral, and this collateral often relates to the item in question. So, if the item does not have proven value to the financier — that is, if it cannot be repossessed and have a guaranteed resale value comparable to the prorated value of the loan — then it may not be financable.

STEP 7.

Start The Permitting Process.

If you have successfully arrived at this point, then now is the time to proceed with obtaining the necessary permits. There is a lot of red tape and hassle along the way -- but persevere! If you approach it with a positive attitude, then you should be successful. **Request help** from the various officials concerned — do not go into demanding everything. See the section on *Regulatory Conflicts* for further information.

STEP 8.

Build Or Buy The Equipment.

Some people will be interested in making or refurbishing as much of their own equipment as possible. They won't be going to the supplier or manufacturer for the whole package, but will want to search out plans and specifications from various sources. A list of these appears in the annotated bibliography under *Plans and Specifications*.

For those who want to buy their equipment, a *List of Manufacturers and Suppliers* is included in the section of the same title.

Whatever approach you take, it is important to be sure of the quality of the materials and equipment you buy. There is some junk on the market. This is a young industry, at least in its modern rebirth, so you will probably encounter some unscrupulous entrepreneurs selling basically untested or worthless equipment. If you are looking to make your system cost effective, you may be attracted to the lowest cost equipment. This may or may not be the approach to take in your particular case. The best way to ensure product quality is to ask the supplier for a list of previous customers in your area. Go to one of these sites, talk to the users, and get their opinions on the equipment.

BUY OR OBTAIN GOOD QUALITY PIPE! Do not use seconds. Use gate valves in your system. A good gate valve takes long enough to shut off the water passage that it creates very little water hammer effect. The pressure wave (water hammer) caused by closing off a high pressure line too quickly can cause severe damage to the pipe. **DO NOT USE BALL VALVES.** A good trash screen at the water intake is also vital to continued system operation.

If you have to build or rehabilitate a dam for your hydro system, go see an engineer and get some advice. Dams can be hazards (usually minor in the case of micro-hydro systems) and their soundness should be ensured.

The powerhouse you build needs only be large enough to house the turbine, generator, electrics and battery storage (if any). Minimum requirements are that it be weatherproof and have a dry floor. Nothing sophisticated is required.

Household-size hydro projects are usually most economically developed as DC-to-AC systems. However, if you are tying in with an existing utility grid, synchronous generating systems can often be installed for less per kilowatt.

STEP 9.

Install And Check Out The Equipment.

During installation and equipment check-out, it is important that you follow all the manufacturer's instructions. **Do not take any shortcuts!** Remember that reputable manufacturers have been in the business for awhile and they know their equipment. If you encounter any problems, contact the manufacturer. He will deal with them. It is much to the manufacturer's benefit to see that the system goes in and functions well.

If you are installing a DC system, install the turbine-generator set as close to the use point as possible. This will keep electrical transmission line losses to a minimum.

Determining The Hydro Potential Of Your Site

* **Flow Measurement**

* **Head Measurement**

* **Power Calculation**

To determine the hydro potential of the water flowing from your spring or in your stream, you must know both the flow rate of the water and the head through which the water can usefully fall. The **flow rate** is the quantity of water, usually measured in gallons or cubic feet, flowing past a point in a given time. Typical flow rate units are gallons per minute (gpm) and cubic feet per minute (cfm). The **head** is the vertical height in feet from the headwater (in the case of a dam) or the point where the water enters the intake pipe (where no dam exists), to where the water leaves the turbine housing.

Flow Measurement

In order to adequately assess the minimum continuous power output to be expected from your hydro unit, you will have to determine the minimum quantity of water that will pass through the system. For this reason, it is important to know both the minimum flow rate of your stream or spring and what portion of this flow you can use for power generation. The percentage of the minimum flow you temporarily divert for power generation becomes a consideration when you are addressing fisheries (fish movement up and down the stream) and questions of aesthetics. One manufacturer suggests that only 25 percent of the dry season flow be used for power generation. This, of course, depends upon your particular case — whether you are using a run-of-the-river system or stored pondage, or if your stream is high head with no evident fish life.

If you are already familiar with the stream's seasonal variations, then you can limit flow measurements to the few months surrounding the driest, or lowest flow. However, if you don't know approximately when the flow is the lowest, you will have to make at least once monthly, but preferably bi-weekly, flow measurements throughout the complete year.

Once your flow data has been compiled, you are in a position to begin some calculations. Was this a dry year or a wet year? To determine this, you will have to get further information, usually from the water resources people in your area. They will have several years' precipitation and snow pack data available, if not for your immediate location then for some nearby major drainage basin. You will have to take a look at this information to see how your measured year fits into the pattern. Once you have determined whether your year was dry, typical or wet, then make the necessary corrections to your data to determine the minimum expected flow rates for your stream.

There is something further which should be noted. If your hydro system will be producing electricity for a household, it will in many instances be a DC-to-AC conversion system, so you will be concerned only with minimum flows. A good flow sampling through the dry season (assuming you know what the dry season is) is usually adequate. However, if you are considering a system considerably larger than for a single household, then you will likely be looking at direct AC systems. You might want to do a little bit more with load projections, particularly with respect to what can be done with the energy at the time of year it is available. This will require some feeling for the maximum and mean stream flows as well as the minimum. In addition, if your system requires a dam, then it becomes vital to know maximum stream flows in order to adequately size spillways for bypassing excess water in order to prevent damage to your installation.

How to measure stream or spring flow:

1.
For small mountain streams or for springs, temporarily dam up the water and divert the entire flow into a container of known size. Carefully time the number of seconds it takes to fill this container.

For example:
If it takes 40 seconds to fill a 55 gallon barrel, the flow rate is 1.375 gallons per second, or 82.5 gallons per minute, or 11 cubic feet per minute.

2
For larger streams, the **float method** can be used. If done carefully, and repeated several times, it can give results accurate enough for most calculations. In order to use this method, you need to know the cross-sectional area of the stream and the stream velocity.

The cross-sectional area should be determined at some easily measured spot in the stream, preferably in the middle of a straight run of the stream. Measure the width (w) of the stream in feet at equal intervals across the width of the stream (see Figure A). Record the depth at each interval and calculate the average depth.

For example:

With a stream cross section as in Fig. A,

d = depth

d1 = 1.0 feet
d2 = 1.3 feet
d3 = 1.2 feet
d4 = 1.8 feet
d5 = 1.0 feet
d6 = 0.8 feet
d7 = 1.1 feet
d6 = 1.8 feet
d9 = 1.3 feet
d10 = 0.7 feet

Total = 12 feet

Average d = 1.2 feet

Next, multiply the width (w) by the average depth (d) to get the cross-sectional area (A) of the stream in square feet.

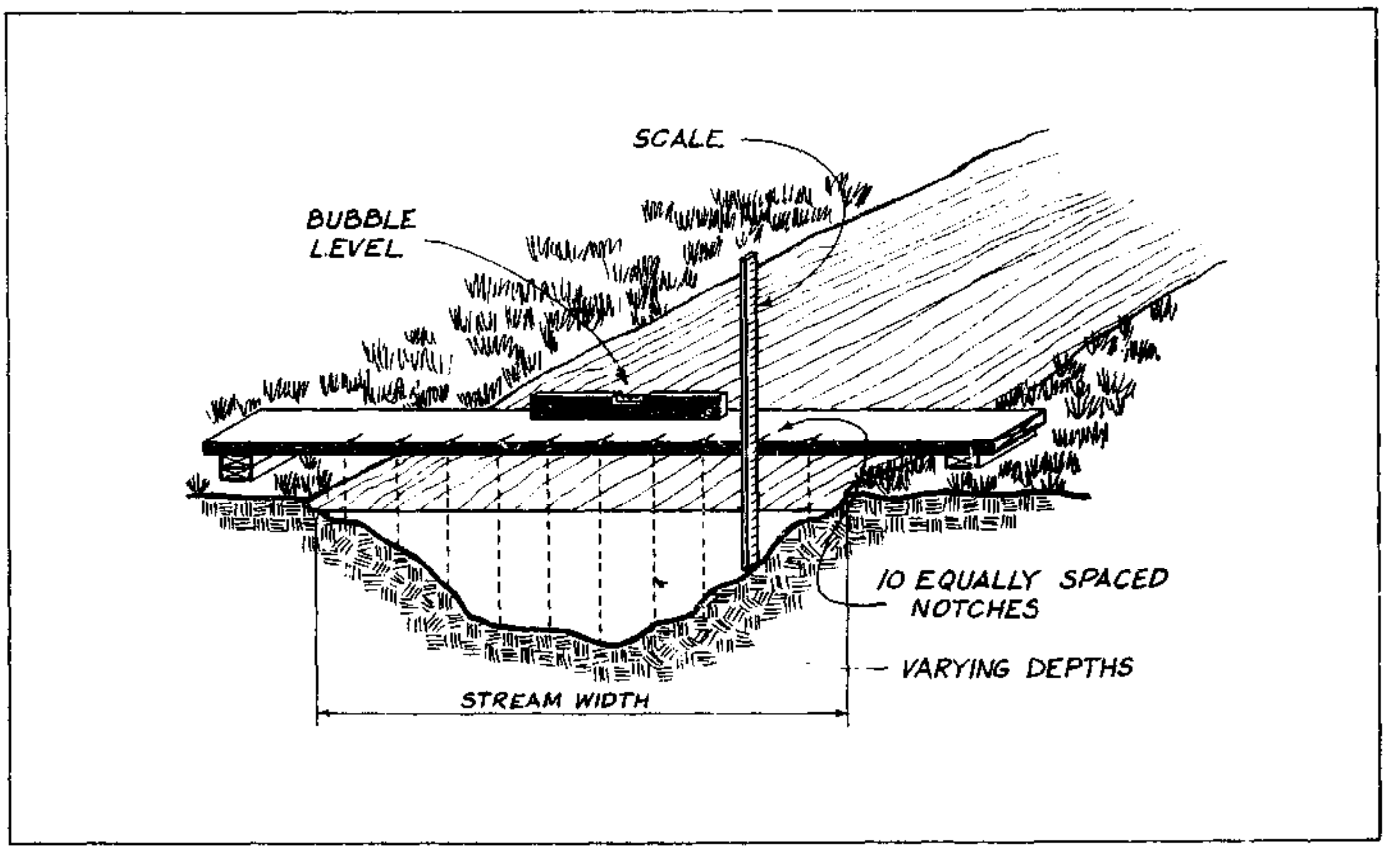


FIGURE A

For example:
In the above stream, say the width at the point of making the depth measurements was 8 feet, then the cross-sectional area (A) is:

A = w x d
A = 8 feet x 1.2 feet
A = 9.6 square feet

The stream velocity can be determined by choosing a straight stretch of water at least 30 feet long with the sides approximately parallel and the bed unobstructed by rocks, branches or other obstacles. Mark off two points, say 30 feet apart, along the stream. On a windless day, place a float upstream of the first marker, in midstream. A pop bottle, partially filled with small stones so that it rides with its neck out of water, is a good float. Carefully time the number of seconds it takes the float to pass from the first marker to the second. Repeat this process several times and average the results.

For example:
The average time for a float to travel between two markers placed 30 feet apart is 15 seconds. The velocity of the float is thus:

$$\frac{30 \text{ ft.}}{15 \text{ sec.}} = 2 \text{ feet/second}$$

This float velocity does not, however, represent the velocity of all the water in the stream. The water at the sides and bottom of the stream flows less quickly than that at the center or near the top due to stream bed friction and channel roughness. A correction factor, depending on the roughness or smoothness of the stream bed, is usually included to give an estimated average stream velocity. This correction factor can vary from 0.6 for a rocky hill stream, to 0.85 for a stream with a very smooth bed and sides.

For example:
Taking the float velocity computed above, the stream velocity (V) for a fairly rough hill stream is

V = 2 feet/second x 0.65 = 1.3 feet/second
or V = 78 feet per minute.

The flow rate of the stream can now be calculated by multiplying the cross-sectional area of the stream (A) by the stream velocity (V).

For example:
Flow = A x V
Flow = 9.6 sq ft x 78 ft/min
Flow = 748.8 cubic feet/min

Now, depending on what portion of the stream flow you can or want to use, you can now determine the usable flow. Simply multiply the stream flow rate you have just calculated by the portion of the flow you will be using.

For example:
If you will only be using 25 percent of the minimum stream flow, and the stream flow you have determined above is 748.8 cubic feet per minute, then the usable flow is:

Usable Flow = 748.8 cfm x 0.25
Usable Flow = 187.2 cfm

There is a third method for determining stream flow. This is called the **Weir Method.** This method is accurate and can be used to measure the flow rate of any stream. It is particularly advantageous for flow measurements in shallow streams where a weighted float would have difficulty floating freely. However, it is also a more complicated technique for measuring flow.

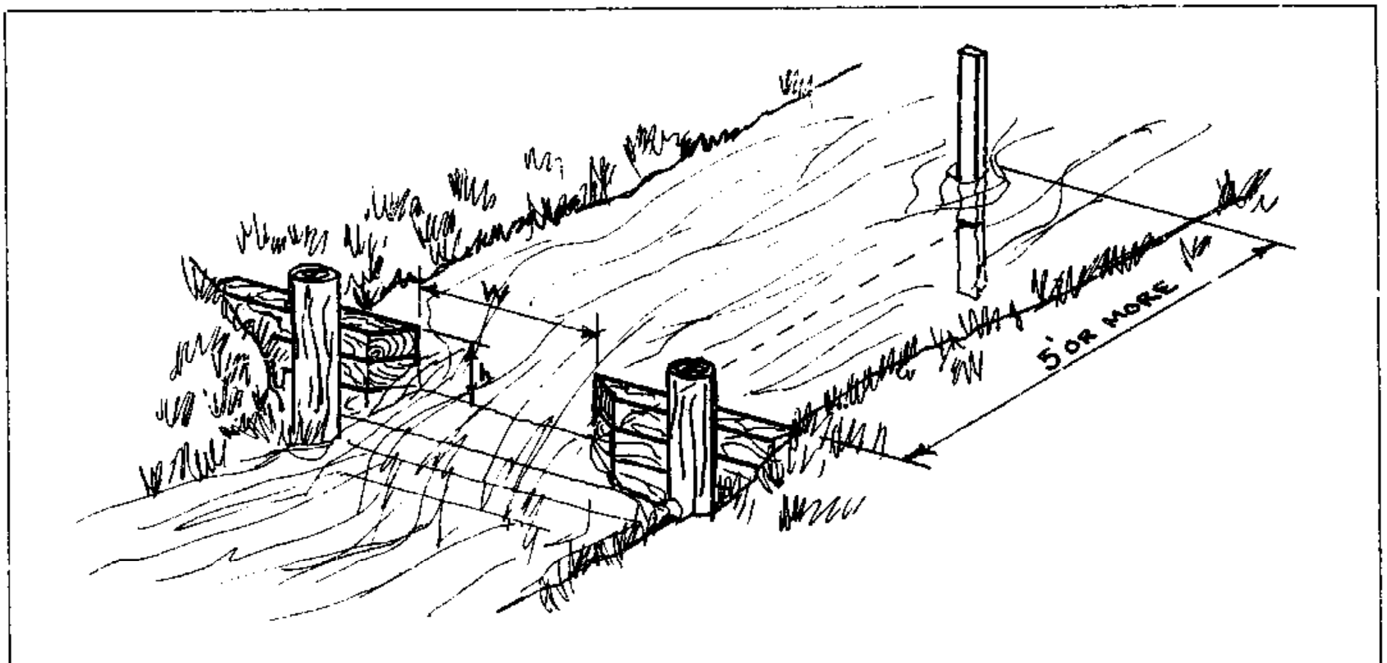


FIGURE B

Essentially, a temporary dam structure is built across the stream perpendicular to the flow, with a rectangular notch or spillway of controlled proportions located in the center section. This notch has to be large enough to take the maximum flow of the stream during the period of measurement, so make some rough estimate of the stream flow prior to building the Weir. The notch width (W) should be at least three times its height (h) and the lower edge should be perfectly level. The lower edge and the vertical sides of the notch should be beveled with the sharp edge upstream. The whole structure can be best built out of timber with all edges and the bottom sealed with clay, earth and sandbags to prevent any leakage. A typical Weir is illustrated in Figure B.

In order to measure the flow of water over the Weir, you have to set up a simple depth gauge. This is done by driving a stake in the stream bed at least 5 feet upstream from the Weir, until a pre-set mark in the stake is precisely level with the bottom edge of the notch. The depth of water on this stake, above the pre-set mark, will indicate the flow rate of water over the Weir. You will need to refer to a "Weir Table" in order to determine this flow rate. A typical "Weir Table" follows:

WEIR TABLE

Depth of stake in inches	c.f.m. per inch of notch width	Depth of stake in inches	c.f.m. per inch of notch width
1	0.40	13	18.87
1.25	0.55	13.25	19.42
1.5	0.74	13.5	19.97
1.75	0.93	13.75	20.52
2	1.14	14	21.09
2.25	1.36	14.25	21.65
2.5	1.59	14.5	22.22
2.75	1.83	14.75	22.70
3	2.09	15	23.38
3.25	2.36	15.25	23.97
3.5	2.63	15.5	24.56
3.75	2.92	15.75	25.16
4	3.22	16	25.76
4.25	3.52	16.25	26.36
4.5	3.83	16.5	26.97
4.75	4.16	16.75	27.58
5	4.50	17	28.20
5.25	4.84	17.25	28.82
5.5	5.18	17.5	29.45
5.75	5.54	17.75	30.08
6	5.90	18	30.70
6.25	6.28	18.25	31.34
6.5	6.65	18.5	31.98
6.75	7.05	18.75	32.63
7	7.44	19	33.29
7.25	7.84	19.25	33.94
7.5	8.25	19.5	34.60
7.75	8.66	19.75	35.27
8	9.10	20	35.94
8.25	9.52	20.25	36.60
8.5	9.96	20.5	37.28
8.75	10.40	20.75	37.96
9	10.86	21	38.65
9.25	11.31	21.25	39.34
9.5	11.77	21.5	40.04
9.75	12.23	21.75	40.73
10	12.71	21	41.43
10.25	13.19	22.25	42.13
10.5	13.67	22.5	42.84
10.75	14.16	22.75	43.56
11	14.67	23	44.28
11.25	15.18	23.25	45.00
11.5	15.67	23.5	45.71
11.75	16.20	23.75	46.43
12	16.73	24	47.18
12.25	17.26		
12.5	17.78		
12.75	18.32		

To use the table, determine the depth of water in inches over the pre-set stake mark. Take this value to the Weir Table and read off the flow rate in cubic feet per minute per inch of notch width. Multiply this volume flow rate by the width, in inches of your Weir notch. This will give you the stream flow rate in cubic feet per minute.

For example:
On a particular stream you have built a Weir with a notch width of 30 inches. The depth of the water on the stake above the pre-set marking is 6¼ inches. On the Weir Table, read opposite 6.25 inches to the flow rate of 6.28 cfm per inch of notch width. The flow rate of the total stream is then:

6.28 cfm x 30 in.
or 188.4 cfm

When you have the Weir in place, you can easily take readings at your convenience. If you are going to use the Weir for any extended period of time, it is important to frequently ensure the watertightness of the sides and bottom.

Head Measurement

The greater the vertical distance that water falls, the more potentially useful power there is available in the water.

How to measure head:

1.

For high head systems, detailed topographical maps of your area may give some indication of the vertical height difference between proposed intake and tailwater levels. However, the accuracy of map reading is limited so this technique should only be used for very preliminary estimations.

2.

For those who are acquainted with photographic surveying techniques, this method can give fairly accurate results. Pictures taken in the field can be developed and the elevations scaled on the photographs. But caution — this is not a method for amateurs. Photographic surveying requires some skill and training.

3.

Pocket altimeters can give you preliminary estimations of the elevation difference between intake and tailwater locations on proposed high head systems. However, the accuracy of measurement is not suitable for any serious calculations.
There are some larger portable altimeters on the market, which tend to be very expensive, that can enable you to make elevation measurements within an accuracy of a couple of feet. These instruments are suitable for engineering calculations; however, they do not give as precise measurements as do the following three methods.

4.

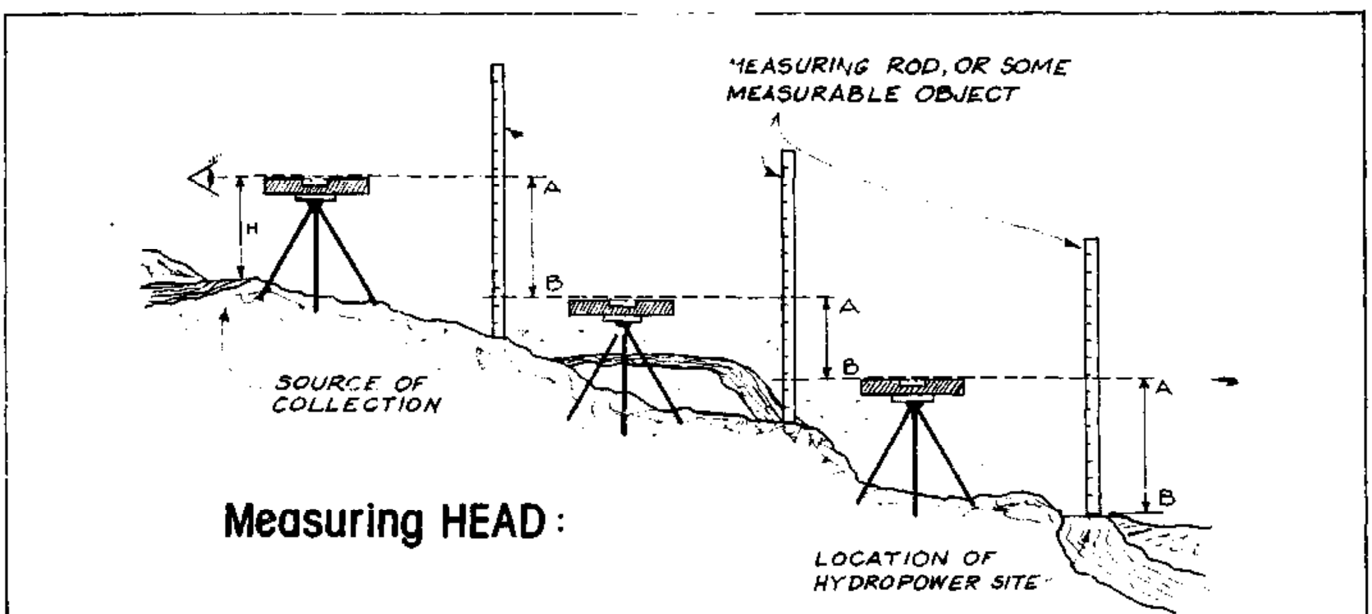
Any good surveyor can be hired to determine the head for you. Ask the surveyor to simply find the vertical distance between your water source, or proposed intake location, and the proposed location of the power plant. Hiring a surveyor is going to be somewhat expensive, so if this is your only alternative, you want to be reasonably sure that you intend to carry through with the project. If your head is less than 25 feet, you need very precise measurements, so a surveyor may be advisable.

5.

If you know how to use standard surveying equipment, for example a transit or a surveyor's level and leveling rod, borrow or rent the appropriate pieces and get a friend to help you make the necessary measurements.

6.

Another technique involves a do-it-yourself approach. The equipment required is a carpenter's level, some sort of stand to raise the level a few feet off the ground, and a tape measure. You may or may not use someone else to assist you. The method is described below in relation to the following diagram:



Measuring HEAD:

a) Set the level on the stand; make sure the level is horizontal (level) and that its upper edge is either at the same elevation as the water source, or a known vertical distance above the water surface.

b) Sight along the upper edge of the level to a spot on a nearby object (tree, rock, building) that is further down the hill and which can be reached for measuring.

c) Note this precise spot on the object and mark it (Point A in the diagram).

d) Move your level and stand down the hill slope and set it up again so that this time the upper edge of the level is at some Point B below Point A on the first object, as in the drawing. Mark this Point B and measure and record the vertical distance A to B. Now sight along the upper edge of the level in the opposite direction to another object that is further down the hill.

e) Repeat this procedure until you end up at the same elevation as the proposed power plant site.

f) If more than one set-up was required, add all the vertical distances A-B. If your first set-up was above the water surface, subtract the vertical distance between the water surface and the upper edge of the level from the sum of the vertical distances. You now have the total head.

In undertaking the above measurements there are a few things you should remember:

*You do not need to be concerned with horizontal distances for head determination.

*Every time you re-set the level, its upper edge should be at precisely the same level as Point B (sight back to check).

*You need not travel in a straight line.

Once you have the total, or gross, head, there are various losses to be considered before you can make any theoretical power calculations. The **net head** is required for these calculations.

NET HEAD = GROSS HEAD − LOSSES

Now, losses occur for several reasons. Whenever water flows through a pipe there are friction losses. These friction losses are greater for increased flow rates and also greater for smaller pipe diameters. Elbows and bends in the pipe will also increase friction losses. PVC pipe offers low friction loss, rarely exceeding 8 percent of the gross head. Good steel pipe has twice the friction loss as PVC. Iron, asbestos and concrete pipe all cause higher losses. Typical PVC pipe losses are indicated in the nomograph on Page 15. Any reputable pipe manufacturer or supplier will be able to supply you with the pipe sizes and friction loss information for your particular flow conditions.

Other losses that might occur in your hydraulic system depend on the type of turbine or wheel that you will be using. For example, in an impulse turbine there is a slight head loss due to the vertical distance between the nozzle jet and the tailwater. Overshot water wheels also suffer some inherent loss since the wheel has to run free of, and therefore slightly above, the tailwater. On the other hand, crossflow, Francis and propeller turbines with draft tubes have almost no inherent head losses.

Power Calculation

Once you have determined the usable flow rate and the net head for your particular site, you are in a position to calculate the amount of power you can expect. You will first have to calculate the theoretically available power, assuming that 100 percent of the power available in the water can be usefully converted.

The theoretical power available (P_{th}) is given by the following equation where:

$P_{th} = 62.4\ Q \times h$

Q = usable flow in cfm

h = net head, in feet

62.4 = density of water in lbs/cubic foot

This gives P_{th} in foot-pounds per minute.

To convert this to horsepower, the equation becomes:

$$P_{th} = \frac{62.4\ Q \times h}{33{,}000} = \frac{Q \times h}{529}$$

To convert to Kilowatts, the same equation becomes:

$$P_{th} = \frac{62.4\ Q \times h}{33{,}000} \times 0.725 = \frac{Q \times h}{709}$$

For example:

Using a flow rate (Q) of 5 cfm and a net head (h) of 100 feet, the theoretical power, in Kilowatts is:

$$P_{th} = \frac{Q \times h}{709}$$

$$= \frac{5 \times 100}{709}$$

$$= 0.7 \text{ KW}$$

$$= 700 \text{ Watts}$$

The theoretical power available represents more power than you will get out of your equipment. All of the machinery and other equipment that you use to convert the power available in the flowing water to mechanical shaft or electrical power are less than 100 percent efficient. As an indication, typical efficiencies of water wheels and turbines are listed below. More precise figures are available from the manufacturers.

Typical Efficiency Ranges for Small Water Wheels and Turbines

Prime Mover	Efficiency Range
Water Wheels:	
Undershot	25-45 percent
Breast	35-65 percent
Poncelet	40-60 percent
Overshot	60-75 percent
Turbines:	
Reaction	80 percent
Impulse	80-85 percent
Crossflow	60-80 percent

To transmit the power from water wheel or turbine to a generator, alternator, or some mechanical system also entails losses. Belt drives are 95 to 97 percent efficient for each belt; gear boxes 95 percent and higher; alternators and generators 80 percent. If you use second hand equipment, you can adjust the efficiency rating down slightly.

Typical overall efficiences for electrical generation systems can vary from 50 to 70 percent, with the higher overall efficiencies occurring in the high head, high speed impulse turbines. Overall efficiences of systems using water wheels are usually well under 50 percent.

For example:

Using our previous figures, the theoretical power available (P_{th}) was 700 Watts. If an impulse turbine, with efficiency of 80 percent, is used with a single belt drive to an 80 percent efficient alternator, then the useful power (P) is:

P = 700 Watts x 0.8 (turbine) x 0.95 (belt drive) x 0.8 (alternator)

P = 426 Watts

In summary, here are the steps to follow to determine the hydro potential of your site:

1. Measure the water flow rate using one of the following:

* timed container filling method
* float method, or
* Weir method

2. Determine the usable flow — that portion of the stream flow you can use.

3. Measure the total or gross head, preferably with:

* surveyor's equipment or
* carpenter's level and stand

4. Determine the net head by subtracting friction and other losses from the gross head.

5. Calculate the theoretical power available using either:

$$P_{th} = \frac{Q \times h}{529} \text{ horsepower} \quad \text{or}$$

$$P_{th} = \frac{Q \times h}{709} \text{ Kilowatts}$$

where Q = usable flow rate in cu. ft./min
h = net head, in feet.

6. Calculate the useful power available by multiplying P_{th} by the efficiency of each piece of machinery linked into the system between and including the water wheel or turbine and the unit giving out the useful power.

Once you know the usable flow rate of your stream and the net head, then you can use a nomograph similar to the one above to determine the power you can expect from your turbine. For example, suppose you have a usable water flow rate of 500 gpm through a net head of 50 feet. To determine the power you can expect from the turbine, locate the flow rate, 500 gpm on the **flow** line, and the head, 50 feet on the **head** line. Join these two points with a straight line. The point where this line cuts the **power** line gives three pieces of information. The continuous power output, in generated kilowatts, is 2.5. This means that your turbine will be putting out a constant 2.5 KW if the water flow rate conditions stay the same as assumed. At a continuous power output of 2.5 KW, you can expect to produce nearly 2000 kilowatt hours per month, as indicated on the first scale on the left side of the **power** line. If you are using a DC system, feeding into storage batteries, then your system can have a peak power output of 12 KW, as shown by the brackets.

Sample calculation to illustrate use of nomograph:

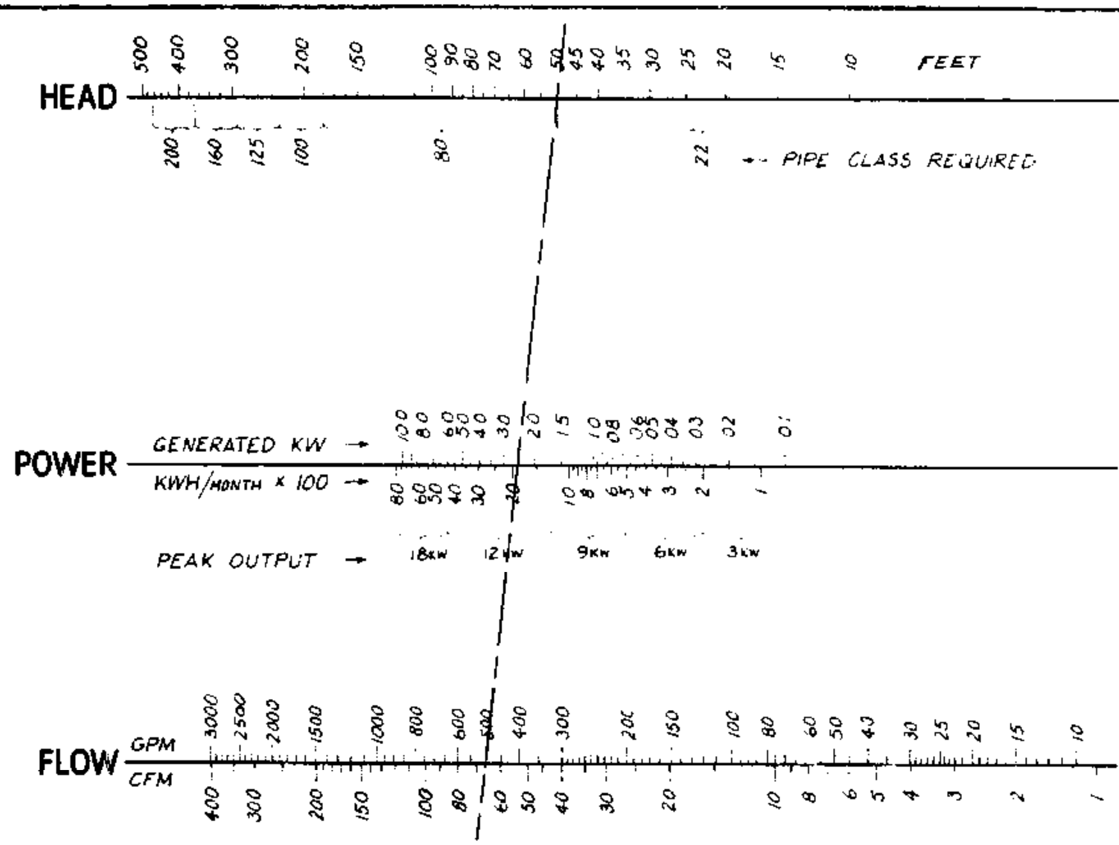
Suppose you have a water flow rate of 500 gallons per minute through a 6-inch diameter PVC pipe. To determine the head loss due to friction, locate the flow rate value, 500 gpm, on the **flow** line, and the pipe diameter, 6 inches, on the **pipe size** line. Using a straight edge, draw a straight line through these two points and continue it to cut the **friction** line. The **friction** line is cut at a value of 1.50, which means that for the pipe size and flow rate given, there is a head loss due to friction of about 1.50 feet for each 100 feet of pipe length used in your system. An extension of this same straight line to intersect the **velocity** line indicates that the water is flowing through the pipe at about 5.8 feet per second.

TYPICAL HOUSEHOLD APPLIANCE LOADS

Appliance	Power Watts	Avg. Hours Use/Mo.	Total Power Consumption KW Hr./Mo.
Blender	600	3	2
Car Block Heater	450	300	135
Clock	2	720	1
Clothes Dryer	4600	19	87
Coffee Maker	600-900	12	7-11
Electric Blanket	200	80	16
Fan (Kitchen)	250	30	8
Freezer (Chest, 15 cu. ft.)	350	240	84
Hair Dryer (hand-held)	400	5	2
Hi-Fi (tube-type)	115	120	14
Hi-Fi (solid state)	30	120	4
Iron	1100	12	13
Light (60-watt)	60	120	7
Light (100 watt)	100	90	9
Lights (4 extra, 75-watt)	225	120	27
Light (flourescent, 4')	50	240	12
Mixer	124	6	1
Radio (tube type)	80	120	10
Radio (solid state)	50	120	6
Refrig. (standard, 14 cu. ft.)	300	200	60
Refrig. (frost free, 14 cu. ft.)	360	500	180
Sewing Machine	100	10	1
Toaster	1150	4	5
TV (black & white)	255	120	31
TV (color)	350	120	42
Washing Machine	700	12	8
Water Heater (40-gal)	4500	87	392
Vacuum Cleaner	750	10	8
Shop Equipment:			
Water Pump (½ hp)	460	44	20
Shop Drill (¼", 1/6 hp)	250	2	.5
Skill Saw (1 hp)	1000	6	6
Table Saw (1 hp)	1000	4	4
Lathe (½ hp)	460	2	1

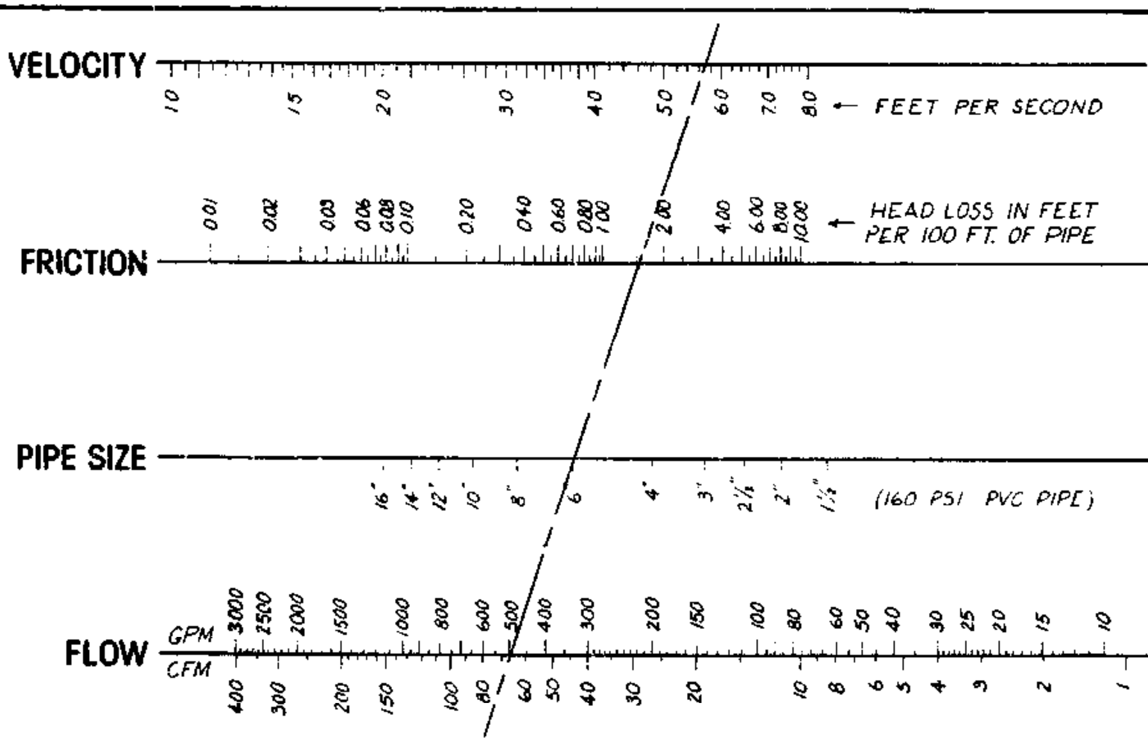
NOMOGRAPH TO DETERMINE TYPICAL OUTPUT POWER FROM A MICRO-HYDRO SYSTEM

(Assumed system efficiency of 53 percent)



Adapted from: Independent Power Developers' brochure "Hydroelectric Power".

NOMOGRAPH TO DETERMINE LOSSES DUE TO FRICTION IN PVC PIPE



Adapted from: Independent Power Developers' brochure "Hydroelectric Power".

Equipment

Turbines

Water Wheels

Sizing the System

Power Generation and Storage

Load Control and Governors

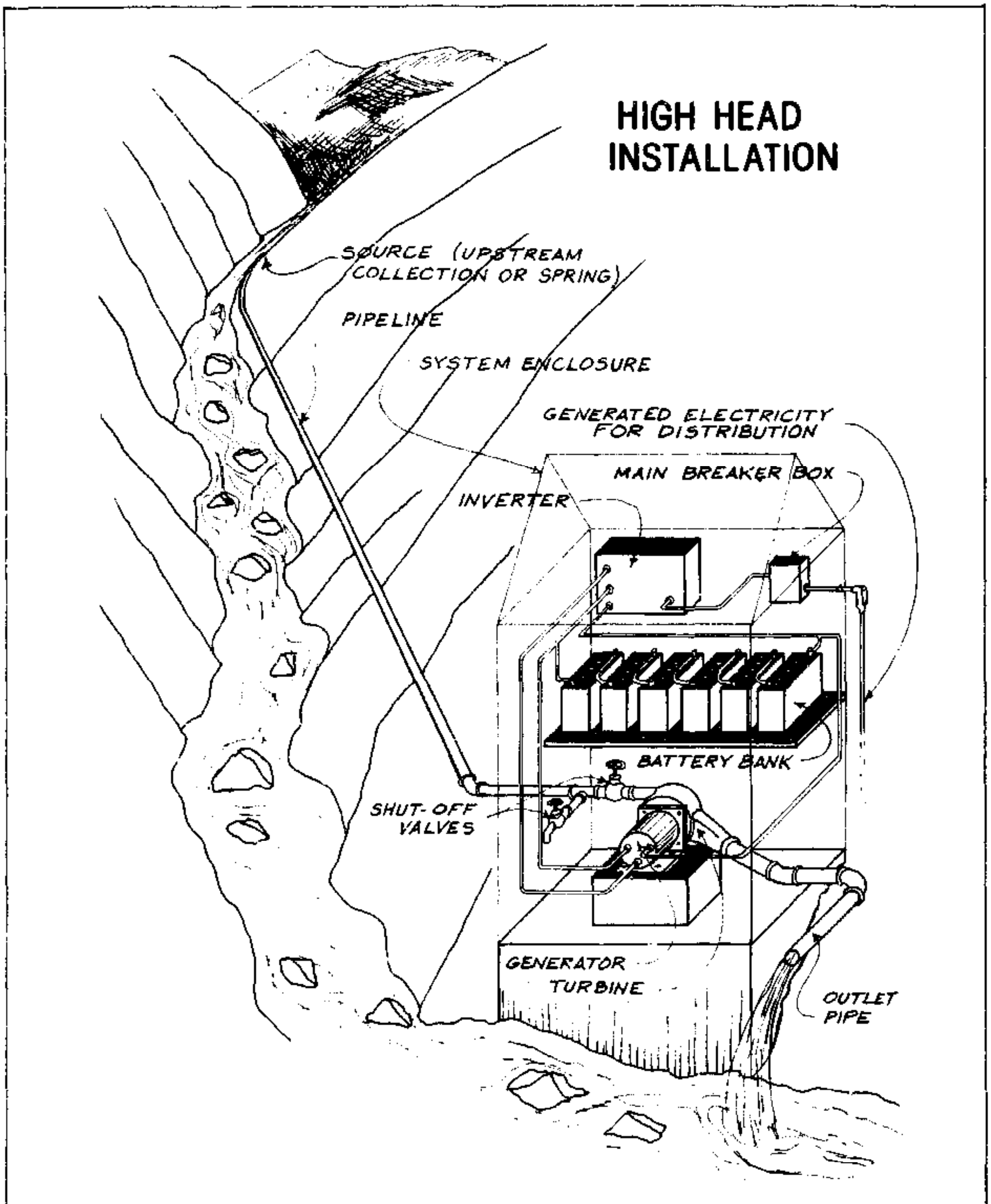
Other Equipment

Turbines

A water turbine is basically a device that converts the energy in falling water into rotating mechanical energy. This energy, available in a rotating shaft, may either be used directly to operate mill and grinding equipment or hooked to a generator to produce electricity. Water turbines take many shapes and have been used around the world for centuries. Although this section will deal primarily with the generation of electricity, references on mechanical applications have been included for those who are interested.

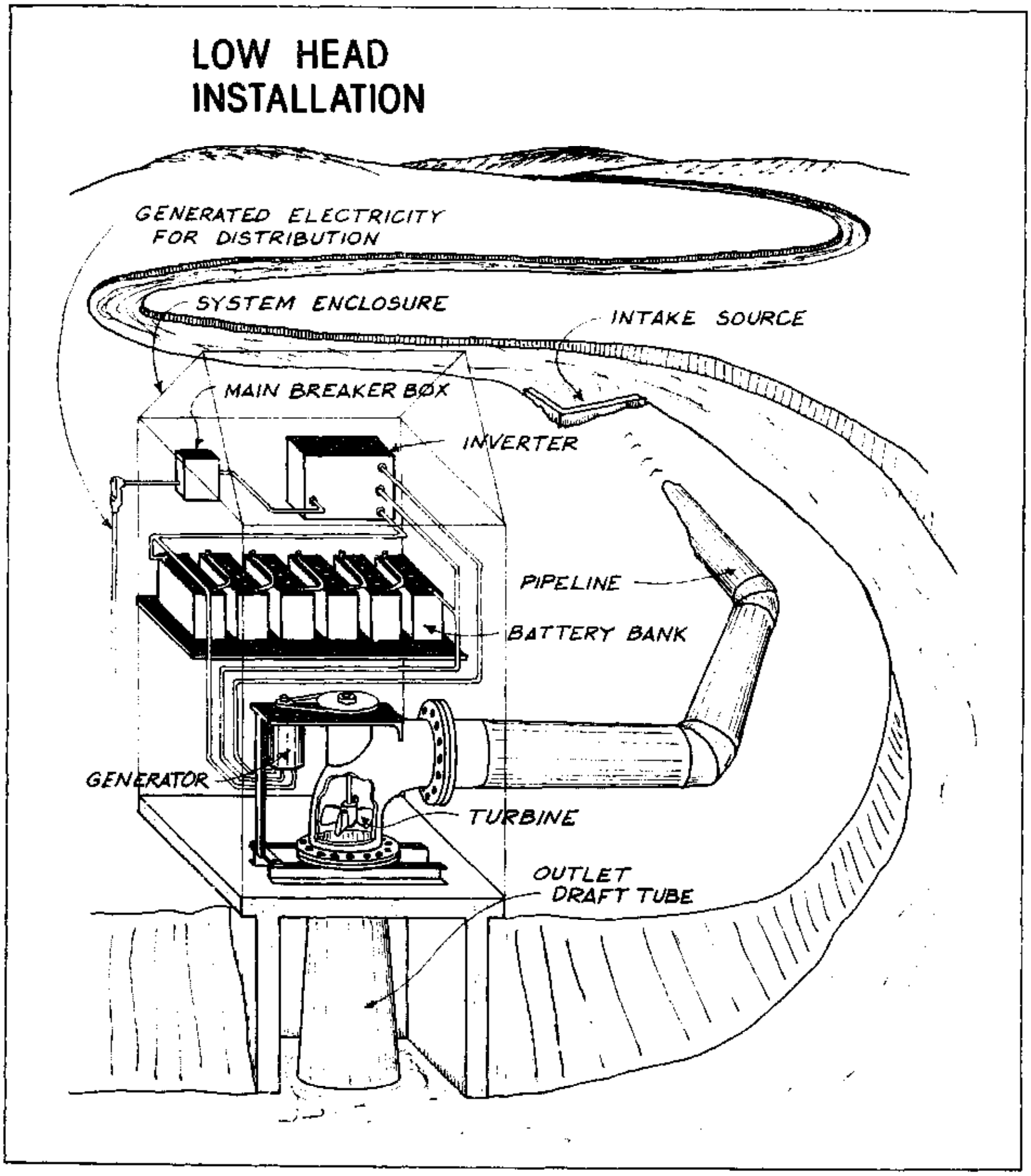
The energy potential that is available at a hydro site is the result of the combination of the "head" and "flow" that is present. It is possible to produce a given amount of power with high head and low flow, low head and high flow, or any combination in between. Sites generally with less than 60 feet are "high head." It is also generally assumed that a head of one meter is the absolute minimum needed to develop hydro power, but less than 10 feet (approx. 3 meters) is probably uneconomical to develop.

Because low head projects require large amounts of



Adapted from: Independent Power Developers' brochure "Hydroelectric Power" water and thus physically large equipment, the resulting unit cost of power generated will be higher than for high head sites with similar power potential. For this reason, most micro-hydro systems being developed in the United States are of the high head type. This is not, however, to say that low head sites are uniformly uneconomical. There are a great many large-scale low head systems operating around the world.

Water turbines are generally very efficient in converting the energy available in the water resource into mechanical and electrical energy. In fact, efficiencies of 70-85 percent are not uncommon. Some turbine designs are intended to operate at a specific flow and their efficiency suffers greatly with any variation, while others are more flexible. Also, because of operating characteristics, turbines are usually designed for a specific application and output. You will generally gain nothing by installing a unit that is larger than your water resource is capable of driving. It is important that you have a good understanding of both your energy requirements and characteristics of the water resource, so that the proper equipment can be selected.



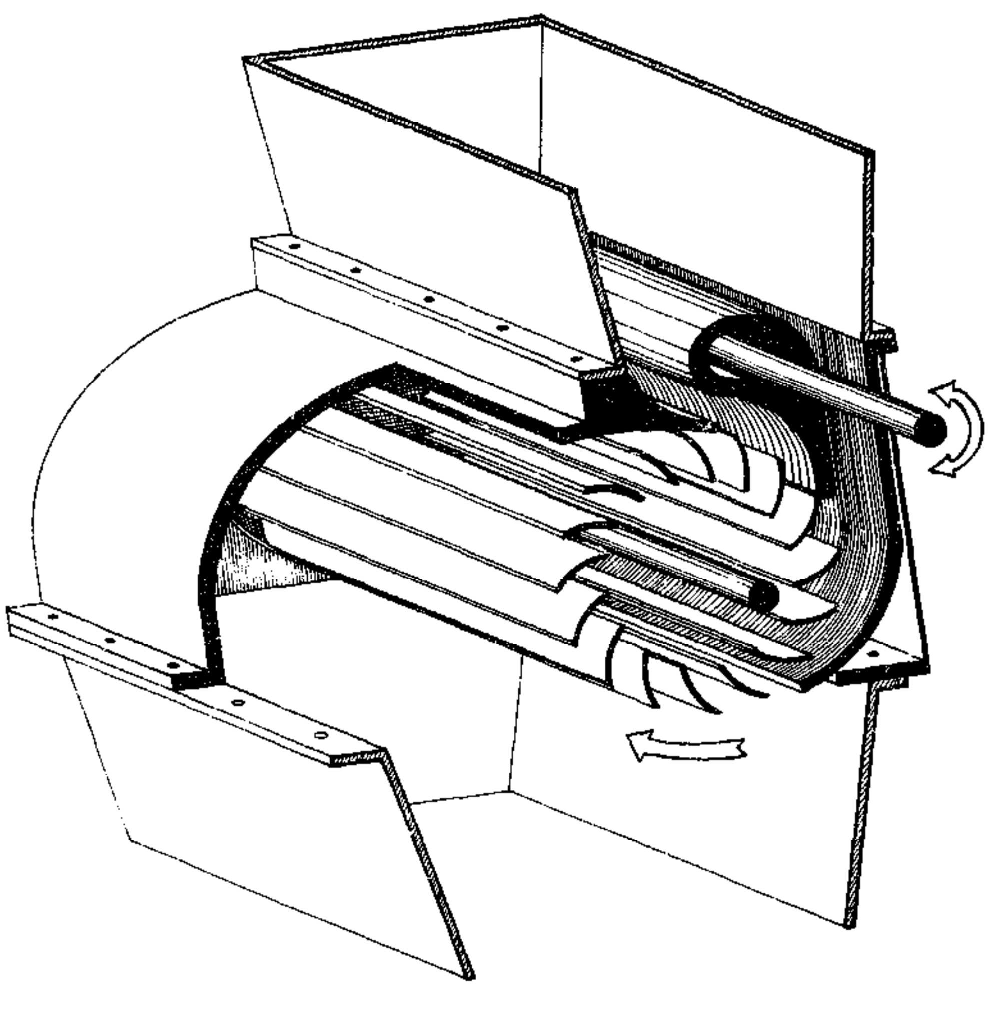
Adapted from: Independent Power Developers' brochure "Hydroelectric Power".

Impulse Units in General

Impulse turbines generally use the velocity of the water to move the runner, rather than using pressure, as is in the case with reaction and propeller designs. Also, because of this, they generally discharge to atmospheric pressure, there is no suction on the down side of the turbine, and the water simply falls out the bottom of the turbine housing after hitting the runner. Impulse units are generally the simplest of all common turbine designs and are widely used in micro-hydro applications.

The Turgo Impulse Wheel:

The Turgo unit is a variation and perhaps improvement on the Pelton. It is made exclusively by Gilkes of England. The Turgo runner is a cast wheel whose shape generally resembles a fan blade that is closed on the outer edge. The water stream is applied to one side, goes across the blades and exits on the other side. The stated advantages of this design are that power equivalent to the Pelton can be produced with a smaller wheel at higher speed. Like the Pelton, it is possible to use more than one water jet on a single wheel in situations where relatively lower head and higher flow are present. Also as with the Pelton, the wheel itself is made in relatively few sizes and different nozzle sizes are used to match the equipment to the site conditions.

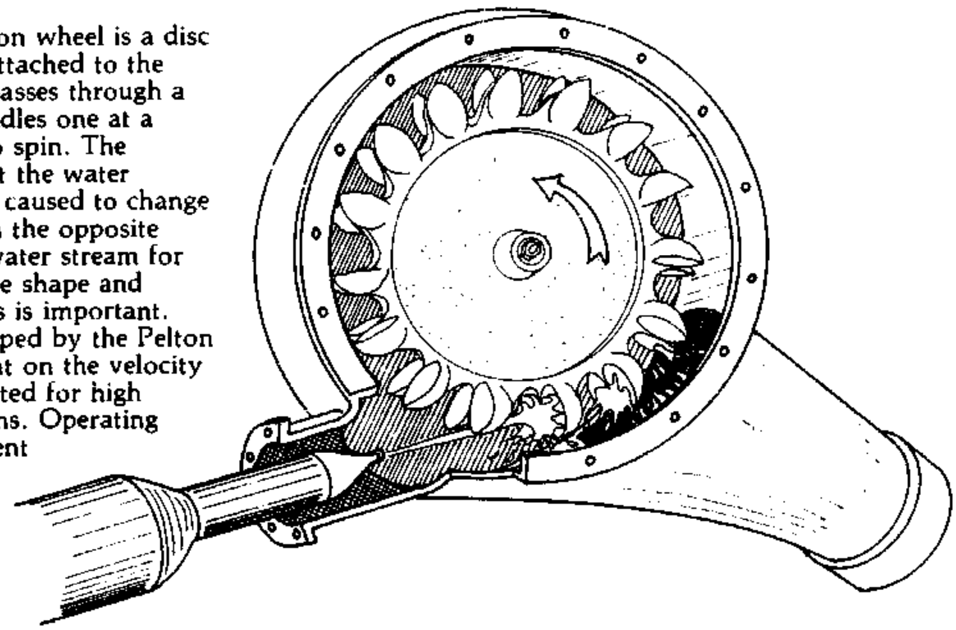


The Crossflow Turbine:

A crossflow runner is drum-shaped with the blades fixed radially along the outer edge. The unit, open in the center, resembles a "squirrel cage" blower. When looked at from the end as though it were a clock face, the water enters at 9 o'clock, crosses the center and exits at 4 o'clock; thus the name crossflow. Most commercially available crossflows are made by Ossberger of West Germany or by someone else under their license. Because of its design, the crossflow is said to be largely self-cleaning and is well suited to low head applications. Ossberger has, in fact, installed them successfully in situations with only 39 inches (1 meter) of head. The Ossberger crossflow uses a metering vane at the intake side and maintains high efficiency over a wide range of flow rates. Because the runner and housing fit fairly close, a draft tube is used on the down side of the turbine, allowing some flexibility in installation relative to turbine placement and tail water level. The crossflow is used widely around the world, although it is less common in the United States

The Pelton Wheel

In general terms, a Pelton wheel is a disc with paddles or buckets attached to the outside edge. The water passes through a nozzle and strikes the paddles one at a time, causing the wheel to spin. The buckets are shaped so that the water stream is split in half and caused to change direction, heading back in the opposite direction to the original water stream for the greatest efficiency. The shape and smoothness of the buckets is important. Because the power developed by the Pelton Wheel is largely dependent on the velocity of the water, it is well suited for high head/low flow installations. Operating efficiencies in the 80 percent range are common and micro units using the Pelton Wheel are produced by several firms in North America.



Reaction Turbines in General

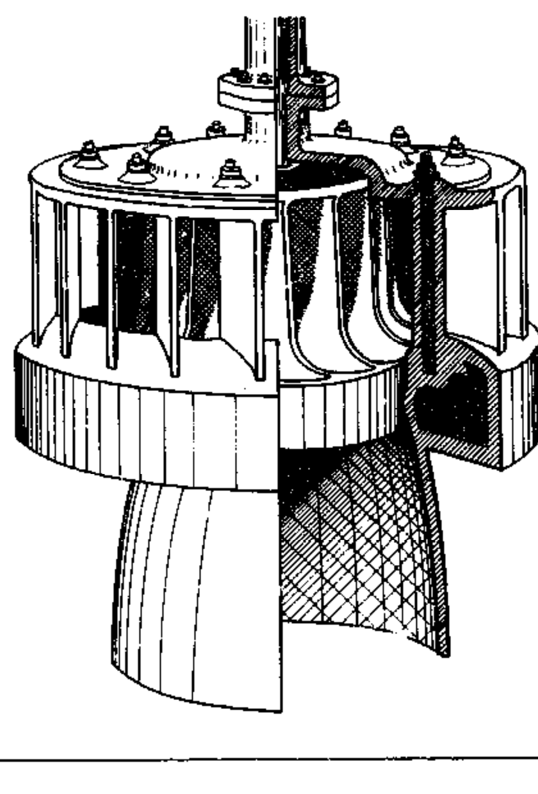
Reaction turbines, while doing the same thing as impulse designs, work on a different principle. The runner is placed directly in the water stream and power is developed by water flowing over the blades rather than striking each individually. Reaction turbines use pressure rather than velocity. The function is more like that of a centrifugal water pump running in its reverse mode. Reaction units tend to be very efficient at specific designed-for situations and their efficiency falls sharply with any variation. The Kaplan design is intended to address that problem. Reaction units are usually the ones used in very large installations.

Propeller Turbines:

This design resembles a boat propeller running in a tube and operates on a similar principle. As with the Francis, the water contacts all of the blades constantly and it is thus imperative that the pressure in the cross section of the pipe be uniform. If, for example, the unit were operating horizontally and the pressure at the top of the tube were less than at the bottom, the runner would be out of balance. There are several variations on how the principle is applied, i.e., the *bulb turbine* in which the turbine and generator are a sealed unit placed directly in the water stream; the *straflow* in which the generator is attached directly to the perimeter of the turbine; the *tube turbine* in which the penstock bends just before or after the runner, allowing a straight line connection with the generator, which is located outside of the pipe. The *Kaplan*, a variation on all of these, has adjustable blades on the propeller to allow for variations in flow rates. Depending on site conditions, the unit can be installed in any position from horizontal to vertical. The most common reaction turbine design used in micro-hydro is the tube, sometimes with the Kaplan blade arrangement.

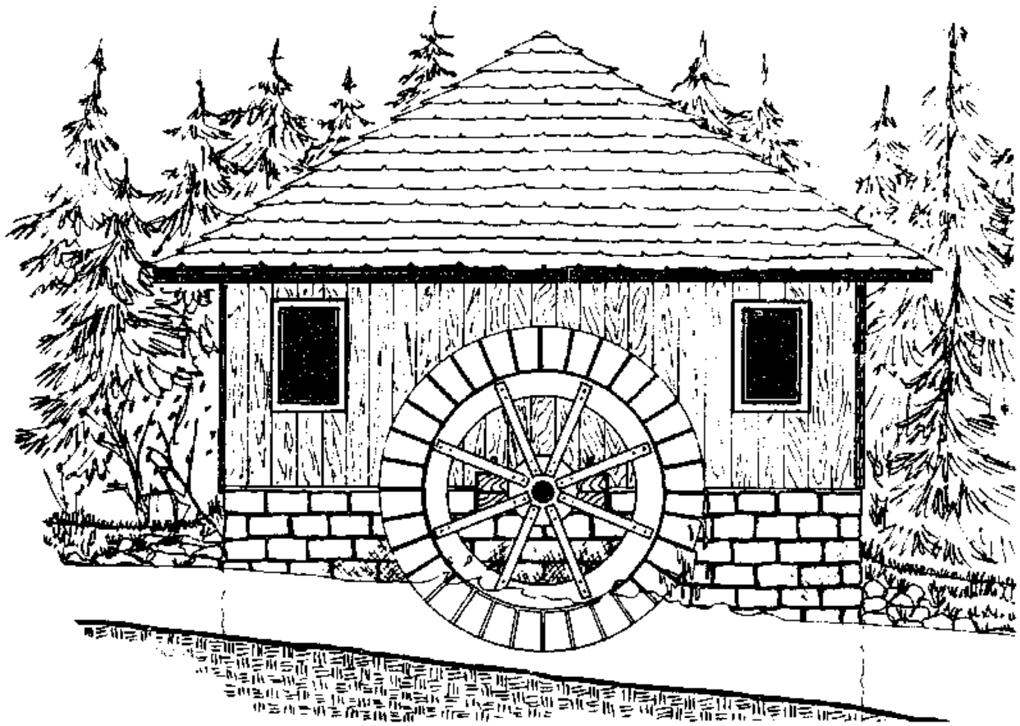
The Francis Turbine:

Francis units are typically installed in very large hydro power developments. The water is introduced just above the runner and all around it and then falls through, causing it to spin. Francis units are designed very specifically for their intended installation, use a complicated valve system, and thus are not generally used in micro-hydro applications.



Water Wheels

Water wheels are the traditional technologies used for converting the energy in flowing and falling water into useful mechanical power. They are usually large diameter, slow turning wheels that are most suited to generating and grinding processes, operating saws, lathes, drill presses and pumps. Or, they can be inefficiently but still effectively used for generating electricity after the rotational shaft speed has been geared up to some suitably higher rpm. Water wheels offer some advantages over higher speed turbines. First, it is quite possible for the individual to construct his/her own water wheel with minimum workshop facilities. Some plans and specifications for water wheel construction are listed in the bibliography. Water wheels can offer high torque and are thus capable of driving heavy, slow turning mechanical equipment. They will operate in situations of large water flow rate variations and they require minimal maintenance and repair. In addition, trash racks and screens are usually not required, since most water wheels can operate with dirt, stones and leaves entrained with the water. The disadvantages of water wheels are several. They are significantly less efficient than higher speed turbines, they operate at slow speed, and they are bulky. As well, in many areas of North America it is necessary to house them in fairly large structures or otherwise provide some protection to avoid freeze-up if year-round operation is required.

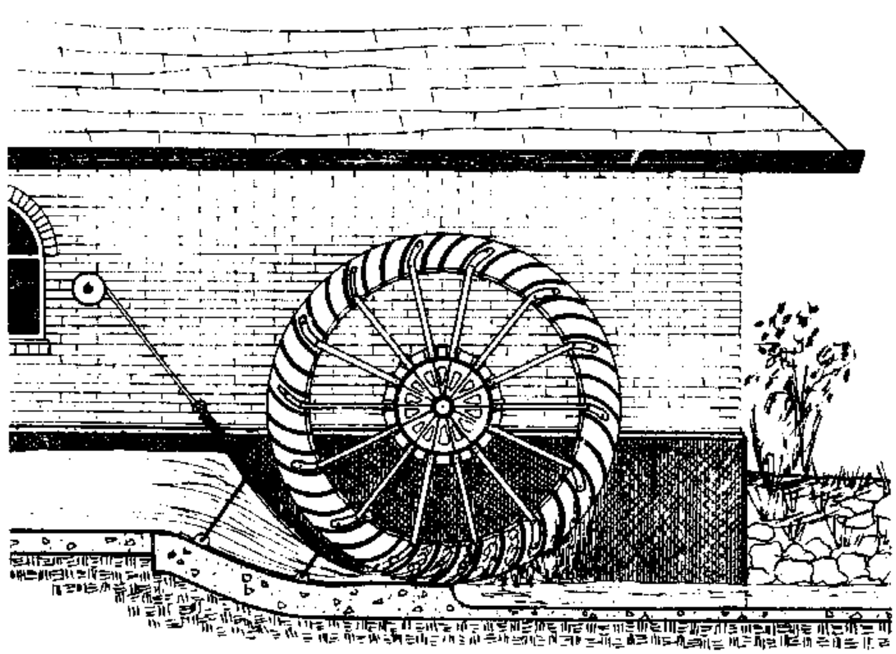


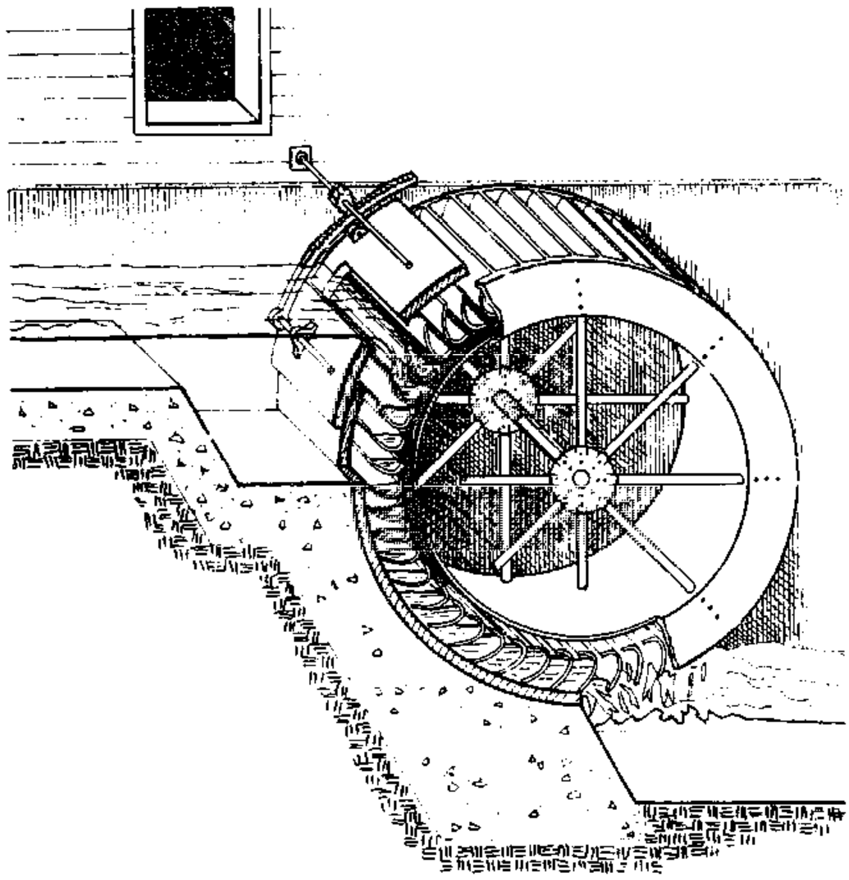
Undershot Wheel:

This is the most basic of water wheels. Water passing under the wheel strikes the blades or paddles, causing the wheel to rotate. It can operate on a minimum of one foot of head (producing almost no power at this head), and has a low efficiency. The optimum head range is 6 to 15 feet, with minimum wheel diameter being about 15 feet.

Poncelet Wheel:

This is an adaptation of the undershot wheel, in which the blades are curved to provide more efficient water interaction with the wheel. This wheel makes use of the velocity of the water which has been held back and forced through a narrow opening. Minimum diameter of a Poncelet Wheel is about 14 feet and they usually operate best with heads of 7 feet or less. Efficiencies are higher than for the undershot wheel. These wheels require a breastworks of concrete fitted close to the rim of the wheel in order to help retain water in the buckets. The close clearances necessitate the use of trash racks to keep stones and wood from entering the system and causing damage.





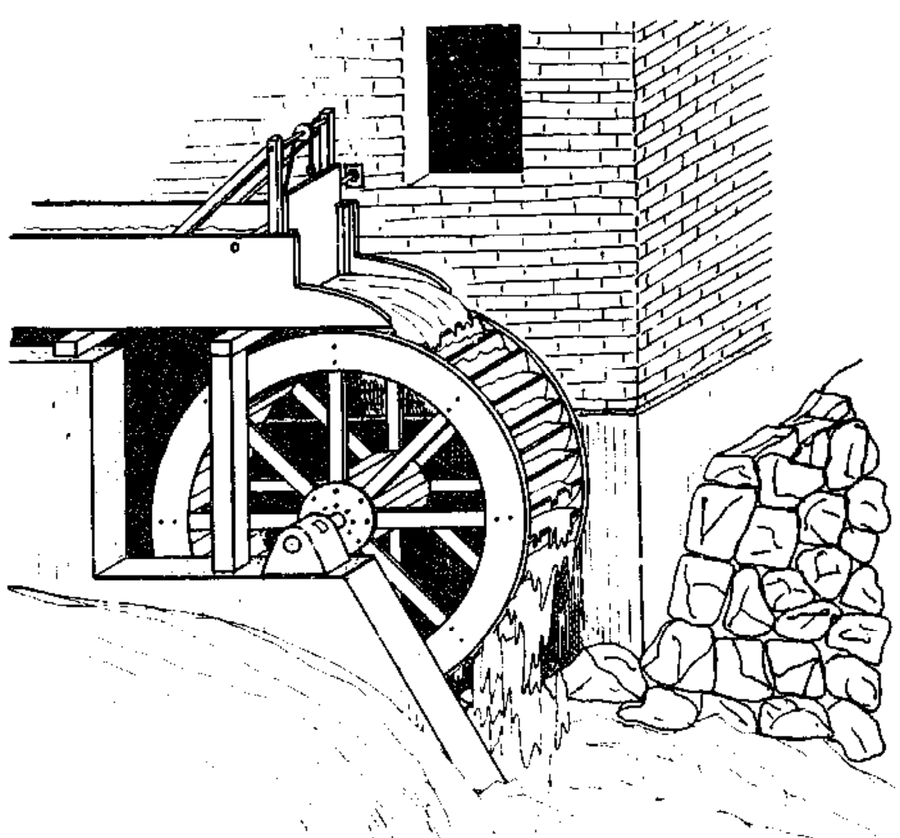
Breast Wheel:

Water enters the breast wheel below the top of the wheel and is kept in the buckets by a close fitting breastworks until it discharges at or near the lowest point on the wheel. Breast wheels operate best with heads less than 10 feet, and wheel diameters usually range between the head and three times the head. High breast wheels (water entering above the center shaft) have efficiencies that can approach 65 percent. Low breast wheels (water entering below the center shaft) usually have efficiencies between 35 and 40 percent.

Breast wheels require somewhat complicated, curved breastworks. In addition, the buckets have to be ventilated to allow air to escape to the next higher bucket as each bucket fills. The close tolerances of the breastworks give the same disadvantages in terms of water-borne debris as for the Poncelet wheel. The complicated construction techniques and the lower efficiencies, particularly in the low breast wheels, usually make other types of water wheels more attractive.

Overshot Wheel:

Water is supplied by a nearly horizontal chute to the top of the water wheel The weight of the water in the rim buckets causes the wheel to turn. The entering water usually strikes the buckets with a velocity somewhat greater than the rim speed so as not to be struck by the back of the buckets and be splashed off the wheel. The water supply, and thus the power output, is controlled by a hand- operated sluice gate. Overshot wheels are generally the most efficient of the water wheels. They can operate on any head above 10 feet. Today, the upper limit on the head is around 30 feet because of the cost of constructing a wheel of that diameter.



Sizing the System

It is important early in your project to examine your power needs and the characteristics of that need. There are two separate but related questions here: **Total Consumption** and **Peak Consumption.**

The total consumption is the number of kilowatt hours used in a given period of time, most commonly KWH per month.

If you are presently getting your power from the utility company, you need only check a number of past bills to get this information. Keep in mind that most household consumption varies by the month, season, unusual changes in weather, or a change in the number of household members. For example, taking consumption figures for the months of June, July and August may not reflect true annual averages. If you are building or buying a new home, you can estimate your power consumption from the Table on **Typical Household Appliance Loads.** If more appliance energy consumption information is required, you can find this in the following books:

Energy Primer
Other Homes and Garbage

The need for accuracy in developing these calculations is real, as over or undersizing the system will result in a system that is either unnecessarily expensive or does not meet your needs.

The peak consumption is the maximum amount of electrical energy needed at any one time.

A second vital concept, *peak consumption,* means simply that if all of the electrical items in the house were operating at once, the resulting power would be the peak. Do not confuse this with total consumption, as the situation could exist where a sytem could meet one need but not the other. In micro systems the peak will be more likely to cause you problems than will the total consumption. As with utility power systems, situations with high peak load relative to the average load will be less efficient and more costly than situations where consumption is more uniform. When analyzing your situation, it may be advantageous or necessary to adjust lifestyles to fit the system rather than buy a system that can cover a high peak consumptive pattern.

If you have access to the utility grid, it will be possible to purchase power needed, but not available from your hydro system, from the power company. It may also be possible to sell your surplus power back to the utility company, although that situation will depend on local policy of the power company and regulatory agencies.

Power Generation & Storage

Mechanical energy is converted to electricity by a generator, similar to the one found in your car. The electricity can be either Direct Current (DC) or Alternating Current (AC). Most, but not all, household appliances run on AC, 110 volts, 60 cycles, and that will be the most useful type of electricity to have.

If you intend to be completely independent from the power grid, a *synchronous generator* is used. AC systems in North America operate at a frequency of 60 cycles per second and any variation from that will affect the accuracy of clocks, phonographs and the like. In order to generate power at this frequency, the speed of the synchronous generator must be very constant and a *governor* is used to control water flow and thus turbine speed. If you have access to utility power, you can use an asynchronous generator with no governor, since it is self-regulating. In either case, the generator must run at its design speed and thus some kind of speed increaser is needed between the turbine and the generator.

Another option is to generate direct current and either use it as-is or convert it to AC when needed through the use of an *inverter.* A DC-to-AC system has several advantages, especially in very small systems (less than 5-KW). The excess power generated by a DC system can easily be stored in batteries, thereby extending the system's peak capacity. DC generators are not speed-sensitive and no governor is needed. Thus, a small DC system will generally cost less and serve needs better than a comparable AC system because a small direct AC unit often cannot cover peak needs. Battery storage systems in hydro units generally work better than those in wind power systems because the hydro generator is always putting some power back into the battery set except in the most extreme cases. This means that a deep discharge condition, common with wind systems, is very rare. Deep discharge is a common cause of battery failure. The storage function does limit the size of a DC system, as batteries become unwieldly and very costly in systems over 6-KW.

With a DC system, it is possible to use only DC appliances, although this is obviously somewhat restrictive and may be expensive if all of your current appliances run on AC. It would, however, save the cost of a DC/AC inverter. For those seeking a lowest cost option, an all 12-volt DC system is possible, as there are many appliances available from recreational vehicle suppliers.

Load Control & Governors

The *governor,* a device that regulates turbine speed through water flow on sychronous generators, is available from a variety of sources. It is reliable and accurate, but does introduce additional cost and maintenance factors.

In systems with no storage capability, some sort of *load control* is needed. Hydro units that have access to the power grid may consider the grid as a sort of storage function, i.e., putting your excess into the grid and buying it back when demand exceeds supply. This concept is currently being used in some areas, but wider use is still open to questions. Otherwise, something must be done with excess power and that is the function of load control units. Such units usually dump excess energy as heat and that heat can often be put to good use such as supplementary space or water heating. When demand begins to approach system capacity, it is possible to use a device that turns key equipment on and off on a priority basis. Non-essential uses are turned off and critical needs are met.

Other Equipment

Dams/Impoundments:

Although many micro-hydro units operate without dams, it may, in some situations, be necessary to build such items into the system. If a dam is required, depending on where you live, you may have to get a registered engineer to design it or at least approve your plans. Good dam plans and construction techniques are described in a number of books, among them:

Cloudburst
Design of Small Dams
Small Earth Dams
Ponds for Water Supply and Recreation

Powerlines:

If the hydro unit is any distance from the house, you will obviously need powerlines. Keep in mind that the longer the distance, the larger the wires that will be needed to avoid unreasonable power loss. This is especially true of 12-volt systems which require very large wire to avoid excessive losses.

Economics

Any analysis of the economics of a micro-hydroelectric system must begin with a determination of the system's true total cost. An investment of this size requires that your calculations be as accurate as possible. This cost calculation must include not only the turbine and generator, but also any pipe, cable, buildings, dam, civil engineering work, permits, legal work and the like. You then have to consider the other options available for electric power and determine their costs. An important consideration that might help the economics of developing a micro-hydro system is the other uses that can be made of the water resource. Fire suppression, domestic water supply and irrigation might involve additional expenses if they had to be developed separately. But because there is very little extra cost to develop these along with a hydro system, they should be figured into your analysis. One way to do this is to add the costs of developing alternative methods of fire suppression, water supply and irrigation to the cost of obtaining electrical power other than by hydro.

One characteristic of many renewable energy resources is that the "front end costs" are high although the lifecycle costs may be very competitive with conventional energy sources. Small-scale hydro, for example, is fairly expensive to purchase, but except for small maintenance costs the system should provide "free" energy for 10 years or longer. The economic analysis of hydro must include such lifecycle costs. For those who are developing a home some distance from existing powerlines, hook-up costs must be considered when looking at the cost of alternative choices. In many areas of the United States, power companies charge by distance to hook homesteads up to powerlines; sometimes as much as $1.50 to $2.00 per foot. A person living 1 mile from powerlines could thus spend as much as $10,000 to hook-up, thus making the hydro option very attractive.

The cost for hydroelectric systems is generally in the range of $750 to $1500 per kilowatt. Variations of cost will depend on any site work that may be needed, the unit's size (cost per kilowatt will go down as output goes up), and head (high head units are generally cheaper than low head units of equal output).

In the event that your site has access to conventional power, and the water has no other uses, it may be difficult to justify a micro-hydro unit on economic terms unless you are willing to take a very long range view. There are a great many factors that will affect your analysis and any such calculations must be done on a case-by-case basis. For example:

* Will you base calculations on life of the hydro unit, which may be 20 years or more, or some shorter period?
* Are you faced with large hook-up charges from the power company?
* Are tax credits or grants available from the State or Federal Government?
* Is your taxable income sufficient to take advantage of the deductible interest payments on loans?
* How long do you expect to remain at this residence and will the hydro system have market value when you want to sell?
* Is there any opportunity to sell or barter power with neighbors or the electric company?
* How much of the installation and maintenance work can you do yourself?

For a great many people the ideas of self-reliant and self-sufficient lifestyles are very appealing, regardless of economic considerations. However, for most people it is important to separate these ideological considerations from the economic ones. There are a great many people for whom micro-hydro presents a viable alternative and economic arguments are sufficient.

A Sample Economic Analysis

One realistic way to analyze your electric power options is to figure the total cost for each over some period of time and then compute the costs in current dollars. The following is such an analysis, computed at three typical interest rates. The following assumptions have been made:

* The hydro system is a 6 KW, DC-to-AC battery storage unit.

* The total cost for the system is $6,000.

* Total maintenance is $1358 over 15 years ($50 per year with 8 percent annual cost increases).

* The site is near existing powerlines and no hook-up charges are required.

* Utility power costs start at 4 cents per kilowatt hour and increase by 10 percent per year.

* The hydro unit is financed by a 15-year, 10 percent loan.

* Average monthly consumption is 500 kilowatt hours.

* The hydro unit is worth $1800 (30 percent of purchase price) at the end of the 15-year period.

* No tax deductions or credits are used.

The figures shown below reflect the cost for each option in current dollars. The computations were done at three interest rates. It may be helpful to view the differences shown as "profit" or "loss" resulting from having selected one option over another. The actual numbers reflect the investment needed today to cover the cost in 15 years. Were you to invest the amounts shown below at the corresponding interest rates, the revenue generated (principal and interest) would be sufficient to cover the cost of the 6 KW hydro system, including maintenance:

5 percent interest	7.5 percent interest	10 percent interest
$9517.54	$8260.37	$7258.44

If we then subtract the salvage value of the system in 15 years, the resulting figures will show the cost of the system at present prices:

$8651.71	$7652.03	$6827.53

If the same approach is taken with the cost of utility-supplied power, the amounts shown must be invested at different interest rates in order to pay for the power over the 15-year period:

$5086.80	$4249.25	$3600.00

Thus, the cost difference between the two options is shown below:

($3564.91)	($3402.78)	($3227.53)

As can be seen in this example, the hydro option will be somewhat more expensive over the 15-year period, assuming all of the conditions mentioned above. A change in any of the assumptions can significantly affect the economics one way or the other. For example, if the site were one mile from the existing powerline, a hook-up charge would result. Assuming a cost of $1.50 per foot for the new line, the cost of utility power would increase by $7920.00. Figuring this job into the above equation, the hydro system would offer a profit of:

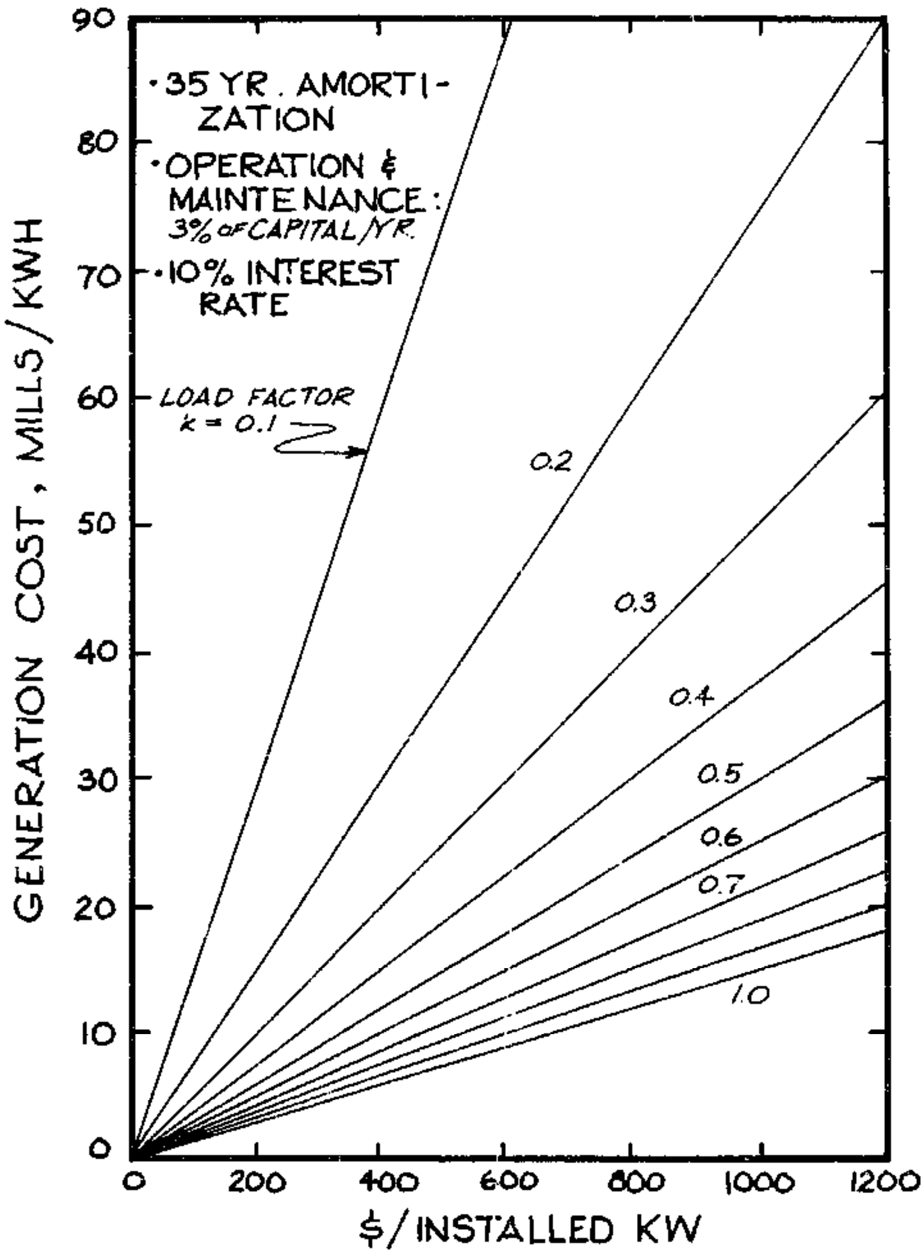
$4355.09	$4517.22	$4692.47

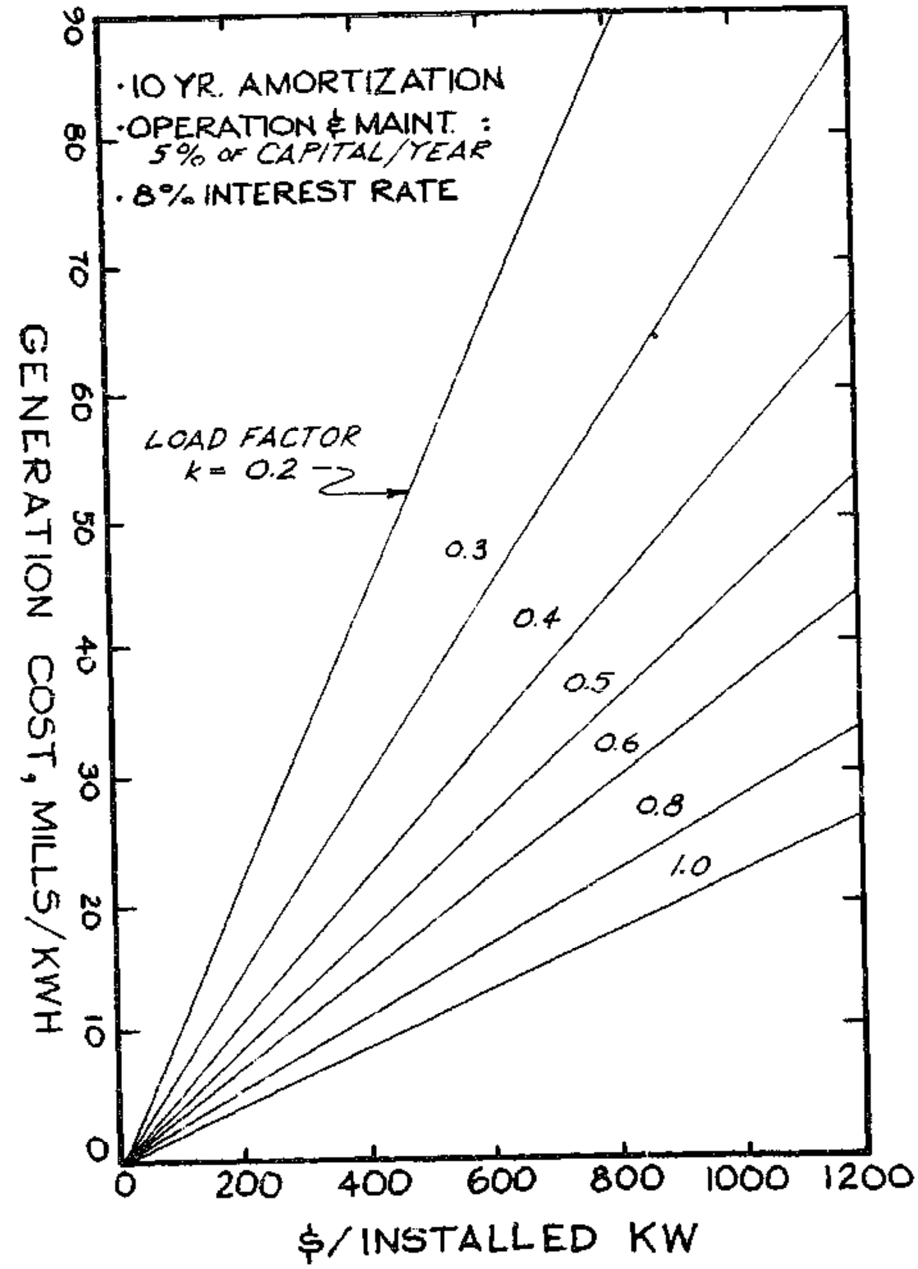
The example shows that for many people, micro-hydro is a viable option; the economics depends heavily on individual conditions. There is also the question of how highly you value independence from traditional energy sources. For some, economic conditions permitting, a small additional cost may be worth the option of unplugging from the power grid.

Another way of looking at the costs associated with installing, operating and maintaining a micro-hydro system is to determine how much all of this will cost you in terms of money spent per kilowatt hour of electricity generated and used. Independent Power Developers have come up with some graphs that can assist you in this estimation. These are reproduced on the following pages. The graphs are set up for various amoritzation periods, operation and maintenance costs and interest rates.

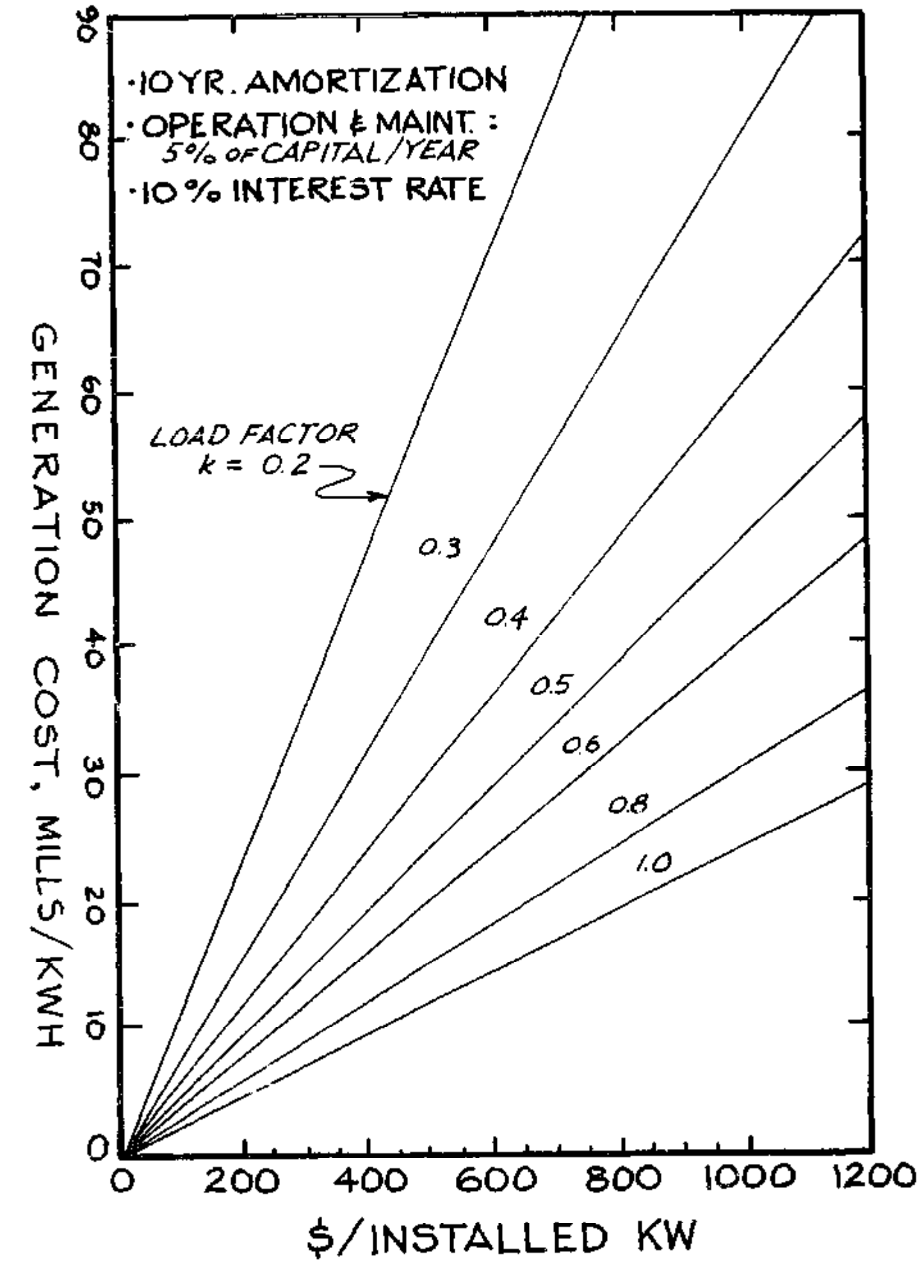
The horizontal axis of each graph is the cost of the micro-hydro installation, given in dollars per installed kilowatt. The vertical axis is the cost of the electrical power generated in mills per kilowatt hour (10 mills equal one cent). The family of lines emanating from the lower left in each graph represents lines of constant load factors. Load factor is simply the average power output of the generating equipment, divided by its rated power output.

What the load factor lines mean, in essence, is that the more you are able to use your electrical power, up to the rated capacity of the system, the closer your system load factor comes to 1.0 and the less per kilowatt hour you spend on electricity. Micro-hydroelectric systems normally have a load factor range between 0.6 and 1.0





·10 YR. AMORTIZATION
·OPERATION & MAINT. : 5% OF CAPITAL/YEAR
·8% INTEREST RATE
LOAD FACTOR k = 0.2
0.3
0.4
0.5
0.6
0.8
1.0
GENERATION COST, MILLS/KWH
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200
$/INSTALLED KW



·10 YR. AMORTIZATION
·OPERATION & MAINT. : 5% OF CAPITAL/YEAR
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LOAD FACTOR k = 0.2
0.3
0.4
0.5
0.6
0.8
1.0
GENERATION COST, MILLS/KWH
$/INSTALLED KW
0
10
20
30
40
50
60
70
80
90
0
200
400
600
800
1000
1200

SOURCES FOR FINANCIAL ASSISTANCE

At the time of this writing, there are several potential sources for financial assistance usable in micro-hydro. This area is rapidly expanding and new programs are likely to be developed.

DOE Small Hydro Program

In 1978, Congress produced legislation that will encourage the development of small-scale hydro (up to 15 MW) on existing dams. The legislation as written will allow $10 million for feasibility studies and $100 million for construction. It apparently was not intended for individual systems, although they are not specifically excluded. The program may be useful for projects of a neighborhood or larger scale.

DOE Small Grants Program

The Small Grants Program, designed to encourage the demonstration of appropriate technologies in general, is administered through regional Department of Energy offices. The regional offices have been allowed some flexibility in their administration, and checking with the office in your area is recommended.

State Grants/Tax Credits

Many states now offer tax credits and/or grants designed to encourage the development of renewable resources. Many of these programs specifically reflect solar, but taken in its widest interpretation, wind and hydro in the broader sense are both solar energies. Check the legislation in your state to see what interpretation is used. Keep in mind that grant programs are often very competitive. In the case of the tax credit, you are generally allowed to deduct some percentage of the system's total cost from your gross income. Be sure to run a quick calculation using your own figures to determine the program's effect on the real cost of your system.

Conventional Bank Loans

One possible source of money is a loan from your local bank. The interest you pay is deductible, but again be sure to calculate real effects in your own situation. People that function in a relatively cash-free economy may derive little benefit from tax deductions. Also, you may encounter some resistance from the bank, as they may be uncomfortable about loaning money on something they don't understand. The development of solar heating systems encountered a similar problem some years ago. With hydro, this is likely to be less of a problem in the future. Also, of course be sure that you are able to afford the monthly payments.

REGULATORY CONFLICTS

A key part of any micro-hydro development program is a study of various institutional and/or legal barriers that may be present and what can or must be done to deal with them. There is a wide range of potential problems in this area, as well as a range of solutions. There may also be some problems for which there are no solutions, or solutions that are too costly to allow the project to proceed. It is best to identify those problems very early in the project time frame and begin what action is needed.

The first step is to **determine the ownership of water rights** for the resource being considered. Law pertaining to water rights varies greatly across the country and a close examination of regulations in your area is important. Generally, you should not assume that because you own the land you also own the water that runs across it. In many states, it is possible to buy land without water rights, as well as buying water rights without owning the land along it. A property owner downstream may own water upstream from that property, or the water may be owned by several downstream users, with each allowed to take some percentage of the flow. In many states the fact that your hydro system will not consume water but only use its energy makes no difference; you must have legal right to use the water. The water right for a particular site may go back a great many years and researching old records may be necessary to determine the true holder of those rights.

Much of the state law regulating water usage was written relative to its irrigation and domestic use, and thus is not directly applicable to hydroelectric systems. This may require new legal decisions in some cases and could mean some hesitancy on the part of the regulatory agency personnel. Do not be discouraged and do not give up because your first response is "no".

A second step is to **secure a water use permit**, which, in some cases, may be required from both state and federal agencies. In some states, having legal right to the water is all that is required. The other situation is when an additional permit is required, referring to the specific use intended. Often the actual installation work must begin within some time period or the permit expires and must be reapplied for. Here again, most water use laws are oriented toward agricultural uses and questions may arise relative to their interpretation in the micro-hydro context.

A federal use permit is generally required when the resource or its development involves federal land, be that Forest Service, Bureau of Land Management, or whatever. An important point to remember is that your use is **beneficial and non-consumptive.** This is different from agricultural or industrial uses which may be beneficial but are also consumptive. Be certain to mention that your intended use is beneficial and non-consumptive, as it should help in the permit process.

The Federal Energy Regulatory Commission (FERC) is the agency that issues licenses for non-federal hydroelectric projects. Because most hydro projects have tended to be very large, with significant environmental issues involved, the FERC licensing process has developed into a lengthy effort. In September of 1978, reflecting the new interest in small-scale hydro development, a new short-form license application was developed by FERC. The short form, which covers projects up to 1500 kW, is only two pages long. However, if the power to be produced by the project would be consumed at the site, the project may not be subject to be licensing by FERC. In which situation, a declaration of intention should be filed pursuant to Section 23(b) of the Federal Power Act, and Part 24 of its Regulations.

The Army Corps of Engineers may have jurisdiction when dredging, filling or other construction takes place in a stream. The interpretation of the applicability of its regulations in this area is the role of the regional Corps office. In any event, it is best to develop the hydro site with the least stream alteration possible. The Army Corps of Engineers is organized by major river basin or drainage areas, and a determination of what basin you are in is the first step in locating the appropriate Corps office.

In those situations where a dam is necessary, a permit will be required from the Corps of Engineers and may be required from state and local agencies as well. There is often some minimum size in terms of dam height and acres of water behind it, and units smaller may be exempt from the permit process. There may also be annual fees, either fixed or variable amount reflecting dam size. These fees are generally modest and are intended to cover the cost of inspection programs. Some states may require that construction plans be done by a registered engineer, which may be a good idea for those individuals who lack engineering skills, but will also raise the cost of the project. Generally speaking, the inclusion of a dam in your hydro project will complicate the effort substantially and thus should be avoided if possible.

A final area for regulatory concern is **environmental impact**. This may include changes in stream flow, blockage of fish movement because of the dam, flooding of some areas above the dam, and the like. The state agency that is most likely to be involved is the Department of Natural Resources, Fish and Wildlife, Conservation or something similar. There may also be federal agencies with jurisdiction, depending on local conditions. In the case of the dams, you may be required to install a fish ladder (a water stairway that allows the fish to move upstream past the dam) and depending on the size and type needed, they can be very expensive. In some states, people intent on redeveloping the power potential of an existing dam have been required to put in a fish ladder even though there had never been one before. Some regulations require that public hearings be held on the proposed development and from a strictly administrative standpoint, these can be very time-consuming. As mentioned above, when planning your hydro project, keep stream disruption to an absolute minimum, and things will go much easier and quicker.

Although it is generally assumed that the power generated by a micro-hydro system will be used by the individual or family that owns it, there are efforts around the country to enter the electric generation business on a small scale. For example, it is now possible to purchase a control unit that when your demand is greater than the sytem's output, the balance is purchased from the power grid (assuming you have access to utility power). When, however, your system is producing more than you need, the control unit feeds the excess back into the grid and in effect winds the electric meter backwards. This type of arrangement makes the power grid a sort of storage battery and may allow the possibility of installing a smaller, less expensive system. It may also affect the income size of the economic analysis by allowing the sale of small amounts of power to the grid. Systems of this type are operating in a few isolated areas and the question is being decided in several others, but generally, widespread usage is somewhere in the future.

For those people who have more generating capacity than they need, it may be feasible to sell or barter the power to a nearby neighbor. In some states the Public Utility Commission will enter the regulatory picture, while in other areas very small projects will be ignored. Also, just as many local governments operate power companies, it may be possible for several families living near a hydro resource to form some kind of power co-op to build and operate the system jointly. Here again, the State Department of Commerce may have jurisdiction and you may encounter opposition from the local power company. Electric companies sometimes interpret their monopolistic license as meaning that no one else can generate power within their service area.

Micro-scale power co-ops and similar arrangements are still very much in their infancy, but may be a viable option for some people.

By way of summary, some general guidelines for approaching the regulatory issue may be valuable. First, develop a clear idea of what you want to do, what the site looks like and how the hydro unit will fit into it. Anticipate questions and develop sound answers. Be able to explain the project clearly to people who will hear of micro-hydro for the first time. Because this is a very new field, you are likely to get a range of fairly negative responses to your first inquiries. Do not be discouraged, but attempt to determine the reason behind his/her response, do what is necessary to correct the situation and continue on.

It will be wise to correspond in writing, make copies and keep a file on all that has transpired. You may want to consult an attorney when dealing with obtuse legal language.

A final word of caution is that you should start checking out these regulatory questions very early, before you buy a lot of equipment or otherwise invest a lot of money. Micro-hydro projects frequently consume one year from first considering the idea until the first kilowatt is generated.

Cautions and Suggestions for the Do-It-Yourselfer and the Self-Installer

The assumption in this section is that you have successfully arrived at Step 8 in the Decision Tree. Now you are entering the final decision and equipment selection stage. The following list of considerations will make installation much easier and avoid a lot of troubles at some future date.

In the final design stage, ensure that you:

1. Consider your stream bed loading conditions. Silt and rocks coming down the stream, particularly during periods of high run-off, can cause intake clogging or even destruction of the intake pipes.

2. Size the pipe so that it is capable of handling the volume flow rate that you require. Any responsible pipe supplier can give you the correct size for the flow conditions you expect.

3. Route the pipeline, from intake to the turbine, so that it contains the minimum number of bends. Do not use 45 degree (or greater) elbows in the pipeline. Otherwise, there will be too much strain on the pipe and excessive friction losses.

4. Keep a downhill slope in the pipe at all times (except for the initial siphon intake, if used) in order to avoid air locks and silt deposit.

5. Do not let the water velocity in PVC pipe get much above 5 feet per second. Above this line velocity there are other design considerations coming into play that the do-it-yourselfer is not usually prepared to deal with. One of these considerations is thrust-blocking wherever the pipe bends.

6. Size the pipe in order to maintain about 5 feet/second line velocity in order to avoid excessive ice build-up in the pipe. If your line velocity is much less than this and you are installing the system in an area where winters are severe, then consider insulating or burying the line.

7. Consider installing a water by-pass before the turbine in case the water may be needed for fire control.

8. Locate the DC turbine and generator adjacent to the point of use. This is important in order to keep electrical transmission lines as short as possible so that line losses are kept to a minimum.

9. Plan to install the system in warmer weather, and not under freezing conditions if at all possible. You are dealing with a liquid that freezes at certain times of the year, and if it does so while you are working with it, it could be dangerous to the equipment and yourself.

When buying or otherwise acquiring your equipment you should:

1. Be sure you deal with a reputable supplier. There is some junk around, so buyer beware!

2. Expect delays in getting quotes and deliveries from equipment suppliers, since none of them are currently very big and they are usually quite busy.

3. Obtain pipe that is rated and classed for the pressure rating it's in. Don't buy seconds.

4. Ensure that you have a good trash control system for the intake. A screen mesh should be used that has openings smaller than the minimum nozzle diameter which leads into the turbine. This way the only solid particles that can come down the pipe will be small enough to pass through the nozzle without clogging it.

During installation:

1. Be sure you follow the manufacturer's or supplier's instructions and suggestions.

2. Slow down and do things properly. You are dealing with mechanical and electrical systems. They can cause you a lot of grief unless treated with respect.

3. Watch for rocks, and be careful placing them, when burying PVC pipe.

4. Use gate valves wherever valving is necessary. Other kinds of valving allow you to turn off the water too quickly, causing dangerous water hammer effects.

5. Use standard house wiring procedures with the electrical hook-up. Go to your local bookstore and pick up the appropriate electrical do-it-yourself book. Or, if you feel unsure of your own capability, go to your local electrician and get him/her to help you.

Once the system is operational, be very sure that you close valves, when you have to, slowly. Take a little time and screw them closed gradually. Closing a valve too quickly can cause a shock wave (a high pressure wave) to move through the water in the pipe. It is going to have some detrimental effect somewhere along the length of that pipe. This damage is going to vary depending on the length of the pipe and the velocity of the water at the point of valve closure. In many cases it will crack the pipe and you will see a slow leak, or again it could cause a serious rupture in the pipeline.

Manufacturers and Suppliers

Prime Movers

Independent Power Developers, Inc. Route 3, Box 285 Sandpoint, Idaho 83864	Pelton and Propeller Units, Complete Systems
The James Leffel Company Springfield, Ohio 45501	Francis/Propeller/Hoppes Units
Gilbert, Gilkes & Gordon, Ltd. Westmoreland, England LA9 7BZ	Wide range of turbines from 10 KW to multi-megawatt, Turgo and Kendal
Small Hydroelectric Systems P.O. Box 124 Custer, Washington 98240	Pelton, with power range 5 to 25 KW for heads from 50 to 350 feet
Ossberger Tubinenfabrik D-8832 Weissenberg Pastfach 425 Bayern, West Germany	Crossflow (Mitchell or Banki Type) turbines of 1 to 1000 KW
Escher Wyss, Ltd. CH-8023 Zurich, Switzerland	400 KW mini-straflow
Barata Metal Works and Engineering PT J.L. Ngagel (109) Surabaya, Indonesia	18 KW (plus or minus) Francis and Crossflow
Jyoti, Ltd. Industrial Area PO Chemical Industries R.C. Dutt Road Baroda 390 003, India	Francis and Turgo sets from 5 to 25 KW, plus some larger units
Officiene Beuhler Canton Ticino, Switzerland	
Westward Mouldings, Ltd. Greenhill Works, Delaware Road Gunnislake, Cornwall, England	Fiberglass Water Wheels
Campbell Water Wheel Company 420 South 42nd Street Philadelphia, Pennsylvania 19104	Water Wheels
Drees & Co. GMBH 4760 Werl/West. Postfach 43 West Germany	Medium to large turbines
G & A Associates 223 Katonah Avenue Katonah, New York 10536	Francis units
Maschinenfabrik Kossler GMBH A-3151 St. Polten St. Georgen, Austria	Small turbine sets of 12 to 1250 KVA rating, plus variety of larger machines

Prime Movers

Karlstads Mekaniska Weskstad Fack S-681 01 Kristinehamn, Sweden	Range of medium sized horizontal axis propeller turbines of 50 to 1800 KW
Niagara Water Wheels, Ltd. 706 E. Main Street Welland, Ontario L3B 3Y4, Canada	Four models of propeller turbines with power in range of 20 to 250 KW
AB Bofors Nohab S-46101 Tollhatten, Sweden	Propeller turbines from 100 to 2000 KW
Barber Hydraulic Turbines, Ltd. Barber Point, P.O. Box 340 Port Colborne, Ontario L3K 5W1, Canada	Propeller and Francis turbines
Elektro GMBH St. Gallerstrasse 27 Winter Thur, Switzerland 8400	Francis, miniature turbines in range 50 to 2000 watts
Canyon Industries 5346 Mosquito Lake Road Deming, Washington 98244	Francis, minature turbine set offering 50 to 750 watts
Briau SA BP 43 37009 Tours Cedex, France	Francis/Propeller turbine sets to 50 KW
Northern Water Power Co. P.O. Box 49 Harrisville, New Hampshire 03450	Axial flow propeller turbines with output range 20 to 250 KW
Land & Leisure Services Priory Land St. Thomas Launceston Cornwall, England	Propeller turbines
Alaska Wind and Water Power P.O. Box G Chigiak, Alaska 99567	Pelton turbines
Pumps, Pipe and Power Kingston Village Austin, Nevada 89310	Pelton turbines
Bell Hydroelectric 3 Leatherstocking Street Cooperstown, New York 13326	Crossflow turbines
Balaju Yantra Shala (P) Ltd. Balaju, Katmandu, Nepal	Crossflow turbines
Maine Hydroelectric Development Goose River, Maine	Belfast turbines
Allis Chalmers Hydro Turbine Division P.O. Box 712 York, Pennsylvania 17405	Large turbines

Miscellaneous Equipment and Suppliers

Windworks Box 329, Route 3 Mukwonago, Wisconsin 53149	Gemini Inverter
Lima Electric Company, Inc. 200 East Chapman Road Box 918 Lima, Ohio 45802	AC Alternator
Woodward Governor Company 5001 N. 2nd Street Rockford, Illinois 61101	Mechanical Governor
Natural Power, Inc. New Boston, New Hampshire 03070	Governor

Sources of Professional Services

P.W. Agnew Department of Mechanical Engineering The University Glasgow, Scotland	Research & Development
Dry Buck Ranch P.O. Box 5 Banks, Idaho 83602	Consulting
Guy Immega Lacqueti Island British Columbia, Canada	Consultant/Author
Intermediate Technology Group, Ltd. 9 King Street London, England WC2E 8HN	Research and Development
Low Impact Technology 34 Martin Street South Melbourne, Victoria Australia	Research & Development
David Master P.O. Box 302 Milford, New Hampshire 03055	Consultant
Niagara Water Wheels, Ltd. Box 326, Bridge Station Niagara Falls, New York 14305	Design/Installation
Mike Harper, P.E. P.O. Box 21 Petersborough, New Hampshire 03458	Consulting Construction Installation
Doug Smith P.O. Box 43 Hanover, New Hampshire 03759	Consultant
Tientsin Elector-/Driving Research Institute Tientsin, China	Research & Development
Bill Delp c/o Independent Power Developers Route 3, Box 285 Sandpoint, Idaho 83864	Consulting Fabrication Installation

BIBLIOGRAPHY

The Banki Water Turbine

Prepared and Published by:

School of Engineering
Oregon State University
219 Covell Hall
Corvallis, Oregon 97331

This is a short pamphlet which is basically a translation of a German paper by D. Banki written in 1917. It includes a good section on the theory of the Banki crossflow turbine as well as runner construction details. Some test data is given on a typical turbine. This paper is only recommended for those serious enough to want to build their own. The approach is quite scientific.

Cloudburst

Edited by Vic Marks
Published by:

Cloudburst Press, Ltd. (1973)
Mayne Island
British Columbia, Canada VON 2JO

This book contains an excellent 30-page section on micro-hydro development. It goes through the standard techniques of measuring head and flow, gives good descriptions of do-it-yourself dam building, and tells you how to build an overshot water wheel and a crossflow turbine. There is also a fairly good section on water wheel design, describing particular features of overshot, breast and Poncelot wheel buckets.

A Design Manual for Water Wheels

By W.G. Owens
Published by:

VITA (1975)
3706 Rhode Island Avenue
Mt. Rainier, Maryland 20822

This is a do-it-yourself booklet intended for use specifically in developing countries. However, it has obvious application in North America as well. It deals specifically with design and construction details of an overshot water wheel for mechanical power.

Energy Primer

Prepared and Published by:

Portola Institute (1978 ed.)
558 Santa Cruz Avenue
Menlo Park, California 94025

This comprehensive information catalogue focuses on small-scale renewable energy systems, among which is water. It devotes 22 pages to basic descriptions of most aspects of harnessing water power. Included are sections on water rights, environmental considerations, measuring available water power, building dams, water wheels and turbines. It gives some construction details on crossflow turbines and the Pelton wheel. Contained also is a list of over 60 water turbine manufacturers around the world.

A Handbook of Homemade Power

By "Mother Earth News"
Published by: Bantam Books (1974)

This book is available in most bookstores. It includes only a brief section on hydro power, including plans for a small water wheel.

Harnessing Water Power for Home Energy

By Dermot McGuigan

Published by:
Garden Way Publishing Co. (1978)
Charlotte, Vermont 05445

This is an excellent book describing all manner of material related to small and micro-scale hydro. It gives a number of examples of installations of the various types of water wheels and turbines in the United Kingdom and the United States. Manufacturers are listed along with their products and outputs. Equipment costs are often included. It contains a good bibliography.

Hydro Power Engineering

By J.J. Doland

Published by:
Roland Press Co. (1954)
New York, New York

This is a good book if you are an engineer and have a background in hydraulics. It is good on theory and describes practical, but larger hydro systems than would be of interest to the homeowner.

Low-Cost Development of Small Water-Power Sites

By H.W. Hamm

Published by:
VITA (1967)
3706 Rhode Island Avenue
Mt. Rainier, Maryland 20822

This 43-page booklet gives a lot of good information for every step in the process of developing small-scale hydro power sites. Descriptions are included of water wheels, a small 12" diameter crossflow turbine and the Pelton wheel. Small earth dam construction is also covered.

Other Homes and Garbage

By J. Leckie, G. Masters, H. Whitehouse and L. Young

Published by:
Sierra Club Books (1975)
San Francisco, California

This book gives a brief 12-page introduction to micro-hydro power. It describes techniques of measuring water flow, gives simple dam construction, and illustrates the basic types of water wheels and turbines. It is not worth buying this book just for the water power section.

Practical Water Power Engineering

By W.T. Taylor

Published by:
Van Nostrand, USA (1925)
Crosby Lockwood, UK (1925)

This is not necessarily a practical book, particularly when it comes to construction and installation of water power systems. However, it does cover, in detail, information on rainfall and run-off, important considerations in determining your stream capacity. Contains good sections on site selection, reservoir and canals and electrical power transmission.

Producing Your Own Power

Edited by Carol Stoner

Published by:
Rodale Press, Inc.
Emmaus, Pennsylvania

This book deals with a variety of renewable energy systems and includes a 40-page section on water power. It includes an adequate section on measuring head and flow and calculating power available. Included is a five-page piece on determining channel, pipe and other head losses. Small earth and rock dams are described, as well as typical water wheel and turbine characteristics and uses. There is also a section dealing with the VITA hydraulic ram.

Use of Weirs & Flumes in Stream Gauging: Technical Note No. 117

Published by:
World Meteorological Organization (1971)
Publications Center
P.O. Box 483
New York, New York 10016

Describes, in very much detail, techniques for making an accurate assessment of stream water flow rates.

Water Measurement Manual

By Bureau of Reclamation (1967)

Available from:
Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

This book gives detailed descriptions of a wide variety of techniques for measuring flow rates with Weirs, flumes, gates, pipes and orifices. It is somewhat broader in scope than the World Meteorological Organization book, but no more useful for the micro-scale hydro developer.

Design of Small Dams

By Department of the Interior (1973)

Available from:
Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

This is an excellent book! It is 816 pages long and fairly expensive, but it may well be worth your while. It describes medium and large-size earth fill dams — including all details from site selection, soil sampling, design considerations and construction techniques. Included are some excellent sections on environmental impacts and code and regulation requirements.

Ponds for Water Supply and Recreation: Agricultural Handbook No. 387

By Soil Conservation Service, U.S. Department of Agriculture

Available from:
Superintendent of Documents
U.S. Government Printing Office
Washington, D.C. 20402

This book does include most of the information you need to know concerning small earth-filled dams. It contains good sections on water needs assessment, site selection, drainage areas required for various pond sizes, spillway requirements, and construction techniques. This book is not directly applicable to small-scale dams, since it deals with large farm ponds built with some heavy equipment; nevertheless, much of the information is easily transferable.

Small Earth Dams: Circular 467

By L.N. Brown

Published by:
California Agricultural Extension (1965)
90 University Hall
University of California
Berkeley, California 94720

This circular describes site selection for small dams, construction, maintenance and management details and has an interesting section on permits and regulations. It is generally applicable to small earth dams anywhere, but is specifically related to California experiences.

Do-it-yourself plans and specifications for water wheel and turbine construction are included in the following publications.

Overshot Wheel
A Design Manual for Water Wheels

5-Foot Diameter Wheel
Handbook of Homemade Power

Overshot, Undershot and Crossflow
Cloudburst

Overshot, Crossflow and Pelton
Energy Primer

Crossflow
Low-Cost Development of Small Waterpower Sites

Crossflow
The Banki-Water Turbine

Water Wheels
Water Power Hydraulic Engineering, 1899

Reprinted in:
Alternative Sources of Energy, No. 14
Route 2, Box 90-A
Milaca, MN 56353

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National Center for Appropriate Technology
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Butte, Montana 59701
Information (406) 494-4572

TECHNICAL MANUAL

Planning a small-scale
hydro-electric installation