Is a Micro-Hydroelectric System Feasible for You?

People with streams flowing through or near their property sometimes wonder if they can use a hydro-electric system to power their home and/or to sell electricity to a utility. Many factors determine the feasibility of hydroelectric systems. These include:

- The amount of power available from the stream, and if it is sufficient to meet power requirements
- Legal restrictions—local, state, and Federal, on the development of the hydroelectric site, and the use of the water
- The availability of turbines and generators of the type or capacity required the cost of developing the site and operating the system
- The rate a utility will pay for electricity you generate (if you connect to their system).

The following is a basic discussion of the issues you should consider and methods that you may use to carry out a preliminary feasibility assessment of a micro hydroelectric system. Consult the reference list at the end of this fact sheet for more information.

How Much Power Is Available from a Stream?

The first step in assessing the feasibility of any hydroelectric system is to determine the amount of power that you can obtain from the stream at your site. The power available at any instant is primarily a product of the flow volume and "head." Flow volume is typically measured in cubic feet per second (cfs) or gallons per minute (gpm), or the metric equivalents. (See *Conversion Factors* below.) Head is a measure of the pressure of falling water, and is a function of the vertical distance that water drops and the characteristics of the channel or pipe (penstock) through which it flows. Head is expressed in feet (or meters). High flow and/or head means more available power. The higher the head the better, because less water is necessary to produce a given amount of power, and smaller, more efficient, and less costly turbines and piping can be used.

Hydroelectric sites are broadly categorized as "low" or "high" head. Low head typically refers to a change in elevation of less than 10 feet (3 meters). A vertical drop of less than 2 feet (0.61 meters) will probably make a hydroelectric system unfeasible. A high flow rate can compensate for low head, but a larger, and more costly turbine will be necessary. It may be difficult to find a turbine that will operate efficiently under very low heads and low flow.

Determining Head

When determining head, you must consider both gross or "static" head, and net or "dynamic" head. Gross head is the vertical distance between the top of the penstock (the piping that conveys water, under pressure, to the turbine) and the point where the water discharges from the turbine. Net head is gross head minus the pressure or head losses due to friction and turbulence in the penstock. These head losses depend on the type, diameter, and length of the penstock piping, and the number of bends or elbows. You can use gross head to approximate power availability and determine general feasibility, but you must use net head to calculate the actual power available. Standard civil engineering books and the references below will tell you how to calculate head loss.

There are several ways to determine gross head. The most accurate technique is to have a professional survey the site. If you know that you have an elevation drop of several hundred feet, a less expensive, but less accurate technique is to use an aircraft altimeter. You may be able to buy, borrow, or rent an altimeter from a small airport or flying club. You will have to account for the effects of barometric pressure and calibrate the altimeter as necessary. You can also roughly estimate vertical drop from U.S. Geological Survey maps of your area. Another option is to use the "hose/tube" method described below. The publications in the reference list below describe other methods.

Whatever method you use, you will need to determine the vertical distance between the point where water will enter the penstock and the point where water will discharge from the turbine. Always be safety-conscious when working near or in a stream, especially in narrow or steep stream channels and fast flowing water. Never work alone. Never wade into water in which you cannot see the bottom and without first testing the depth with a stick.

To perform the "hose/tube" method you will need an assistant, a 20 to 30 foot (6 to 9 meter) length of small-diameter garden hose or other flexible tubing, a funnel, and a yardstick or measuring tape. Begin by stretching the hose or tubing down the stream channel from the point that you have decided is the most practical elevation for the penstock intake. Have your helper hold the upstream end of the hose, with the funnel in it, under the water as near the surface as possible. While he/she does this, lift the downstream end until water stops flowing from it. Measure the vertical distance between your end of the tube and the surface of the water. This is the gross head for the section of stream between you and your helper. Have your assistant move to where you are and place the funnel at the same point where you took your measurement. Then walk downstream, and repeat the procedure. Continue taking measurements until you reach the point where you plan to site the turbine. The sum of these measurements will give you a rough approximation of the gross head for your site. Note that, due to the force of the water into the upstream end the hose, water may continue to move through the hose after both ends of the hose are actually level. You may wish to subtract an inch or two (or two to five centimeters) from each measurement to account for this. It is best to be conservative in these preliminary head measurements.

Determining Water Flow

Environmental and climatic factors, as well as human activities in the watershed, determine the amount and characteristics of stream flow on a day-to-day and seasonal basis. A storage reservoir can control flow, but unless a dam already exists, building one can greatly increase cost and legal complications.

You may be able to obtain stream flow data from the local offices of the U.S. Geological Survey (USGS; posts surface water flow data on a Web site, see Organizations below), the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, from the county engineer, or local water supply or flood control authorities. If you cannot obtain existing flow data for your stream, you will need to do a site survey. Generally, unless you are considering a storage reservoir, you should use the lowest average flow of the year as the basis of the system design. Alternatively, you can use the average flow during the period of highest expected electricity demand. This may or may not coincide with lowest flows. There may be legal restrictions on the amount of water that you can divert from a stream at certain times of the year. In such a case, you will have to use this amount of available flow as the basis of design. There are a variety of techniques for measuring stream flow. For more information on these methods, consult the references below—or your local library—for books that cover hydroelectric systems, surveying, or civil engineering.

A common method for measuring flow on very small streams is the "bucket" method. This involves damming the stream with logs or boards to divert the stream flow into a bucket or container. The rate that the container fills is the flow rate. For example, a five-gallon (or 20 liter) bucket that fills in one minute is a flow rate of 5 gallons per minute (or 20 liters per minute).

You can also try the following method to roughly estimate the flow in streams where it is impractical to attempt the bucket method. This method involves wading across the stream channel. DO NOT TRY THIS METHOD if the stream is fast-flowing and over your calves! You could lose your footing, be swept downstream, and possibly drown. NEVER wade into any stream in which you cannot see the bottom! Use a stout walking stick for balance and support. ALWAYS check the depth and character of the stream bed with your stick before you take a step. Wear a life jacket in slow-moving streams that are over your knee.

To perform this method, you will need an assistant, a tape measure, a yardstick or calibrated measuring rod, a weighted float (a plastic bottle half filled with water to give a better estimate of flow velocity), a stopwatch, and some graph paper. Begin by calculating the cross-sectional area of the streambed during the time of lowest water flow. To do so, select a stretch of the stream with the straightest channel and most uniform depth and width as possible. At the narrowest point of this stretch, measure the width of the stream. Then, with the yardstick, walk across the stream and measure the water depth at one foot (or 30 centimeters) increments across the stream. Be sure to keep the measuring stick as vertical as possible. You may want to stretch a string or rope across the stream with the increments marked on it to assist in this process. Plot these depths on a piece of graph paper. This will give you a cross-sectional profile of the stream. Determine the area of each block or section of the stream by calculating the areas of the rectangles and triangles in each section. (Area of a rectangle = length ´ width; area of a triangle = 1/2 base ´ height.) Add the areas of all the blocks together for the total area.

Next, determine the flow velocity. From the point where you measured the width, mark a point at least twenty feet upstream, and release the weighted float in the middle of the stream. Carefully record the time it takes the float to pass between the two points. Make sure that the float does not hit or drag on the bottom of the stream. If it does, use a smaller float. Divide the distance between the two points by the float time in seconds to get flow velocity in feet (or meters) per second. Repeat this procedure several times to get an average value. The more times you do so, the more accurate your estimate will be. If the float gets hung up or "stalls," start over, or this will throw the average off. Multiply the average velocity by the cross-sectional area of the stream. Multiply this value by a factor that accounts for the roughness of the stream channel (0.8 for a sandy stream bed, 0.7 for a bed with small to medium sized stones, and 0.6 for a bed with many large stones). The result will be the flow rate in cubic feet (or meters) per second.

Keep in mind that this value will be the flow at the time of measurement. You should repeat the procedure several times during the low flow season to more accurately estimate the average low water flow. You do not have to measure the water depth each time. You can simply measure the water depth above or below the water level when you first measured the stream, and calculate the area of greater or less water, and add or subtract this from the baseline area. Alternatively, you may be able to install a gauge (made from a calibrated rod or post) on the bank so that you can easily read the water depth and calculate the cross-sectional area of the stream. You will need to repeat the flow velocity procedure each time, however.

You may be able to correlate your survey data with long term precipitation data for your area, or flow data from nearby rivers, to get an estimate of long-term, seasonal low, high, and average flows for your stream. Remember that, no matter what the volume of the flow is at any one time, you may be able to legally divert only a certain amount or percentage of the flow. Also try to determine if there any plans for development or changes in land use upstream from your site. Activities such as logging upstream from your site can greatly alter stream flows and water quality.

Determining Power

Once you have the flow and head figures, you can roughly estimate the potential power available, in kilowatts (kW), with the following formula:

Gross Head ´ Flow ´ System Efficiency (in decimal equivalent) ´ C = Power (kW), where C is a constant—the value is different in English and metric units.

Examples:

1. 20 feet ´ 2 cfs ´ 0.55 ´ 0.085 = 1.9 kW or: 6 meters ´ 0.05 cms ´ 0.55 ´ 9.81 = 1.62 kW
2. 50 feet ´ 0.8 cfs ´ 0.55 ´ 0.085 = 1.9 kW or: 15 meters ´ 0.02 cms ´ 0.55 ´ 9.81 = 1.62 kW

Note that in the two examples, much less flow is needed at a higher head to produce the same amount of power. Turbine and generator efficiencies depend on make and operating conditions (head and flow). Generally, low head, low speed water wheels are less efficient than high head, high speed turbines. The overall efficiency of a system will range between 40% and 70%. A well-designed system will achieve an average efficiency of 55%. Turbine manufacturers should be able to provide a close estimate of potential power output for their turbine, given the head and flow conditions at your site. There will also be "line" losses in any power lines used to transmit the electricity from the generator to the site of use.

Assuming that the flow in the examples above is available 24 hours per day throughout the year, the stream will produce about 46 kilowatt-hours (kWh) per day, or about 16,800 kWh per year. A turbine/generator that produces 500 watts continuously (12 kWh per day), and includes batteries for power storage, will be sufficient to meet the power requirements of a small house for lighting, entertainment, a refrigerator, and other kitchen appliances. Remember that using energy conservatively in energy-efficient appliances can reduce energy requirements significantly.

Legal Restrictions and Requirements

Use, access to, control, or diversion of water flows is highly regulated in most regions of the country. So is any physical alteration of a stream channel or bank that may effect water quality or wildlife habitat, regardless of whether or not the stream is on private property. If your project will have minimal physical impact, and you are not planning to sell power to a utility, there is a good chance that the legal process will not be too complex.

There are many local, state, and Federal regulations that govern, or will effect, the construction and operation of a hydroelectric power plant. The larger the system, the more complicated, drawn out, and expensive the permitting and approval process will be. Penalties for not having the permits or necessary approvals can be severe. You will not escape the consequences by pleading ignorance. Although the legal process may seem burdensome, the intention of the laws is to protect all users of the resource, including the plant, fish, and animal communities that utilize the water.

When planning a hydroelectric system, your first point of contact should be the county engineer. He or she will be the most informed about what restrictions govern the development and/or control of water resources in your area. Your state energy office (look in the blue pages of your phone book) may be able to provide you with advice and assistance.

The two primary Federal agencies that you will need to deal with are the Federal Energy Regulatory Commission (FERC) and the U.S. Army Corps of Engineers. Try contacting the nearest office to you to see if they will assist you; both may be listed in the U.S. government section of your phone book's blue pages.

FERC is responsible for licensing all non-Federal government hydroelectric projects under its jurisdiction. A hydroelectric project is within the jurisdiction of FERC if any of the following conditions apply: the project is on a navigable waterway; the project will affect interstate commerce (i.e., if the system is to be connected to a regional electric transmission grid); the project uses federal land; or the project will use surplus water or waterpower from a federal dam. You will need to consult with FERC in order to determine whether or not your project falls under FERC's jurisdiction. If it does, then you will need to apply for a license or exemption from FERC. The FERC application process will require contacting and consulting other Federal, state and local government agencies, and providing evidence that you have done so. If your project involves a discharge of dredge or fill material into a watercourse or wetland, you may also need a permit from the Army Corps of Engineers. Your local district office of the Corps should help determine if you will need a permit.

You will also need to determine whether, and to what extent, you can divert water from the stream channel, and what restrictions apply to construction and operation of the system. Each state controls water rights, and you may need a separate water right to produce power, even if you already have a water right for any other use. You should contact the proper state authorities to obtain this right. The local fish and game or wildlife agencies may be very influential in determining the ultimate design and operation of your system.

Other Federal government agencies that may require permits include: the U.S. Fish and Wildlife Service; the Federal Aviation Administration (if a power line will be constructed near an airport); and the U.S. Forest Service or Bureau of Land Management, if the project will use land administered by these agencies.

Finding Small-Scale Turbines and Generators

Only a few companies make very small, or "micro," hydroelectric turbines, and most are high head turbines. Low head, low flow turbines may be difficult to find, and may have to be custom-made. It is possible to fabricate low to moderately efficient water wheels and turbines in a well-equipped metal workshop. You may be able to find and refurbish old but operable turbines at abandoned hydro/mill sites. Commercially available turbines and generators are usually sold as a package. Do-it-yourself systems require careful matching of a generator with the turbine horsepower and speed.

Selling Power to a Utility

The Public Utility Regulatory Policies Act (PURPA) of 1978 requires electric utilities to purchase power from independent power producers if certain conditions are met. You will need to contact your local utility and/or public utility commission to determine what these technical and operating requirements are, and the price that the utility will pay you for the electricity you generate. You may also need a license from FERC. The utility will require that you insure the system. The interconnect requirements and insurance premiums may cost more than what you earn from selling the power. An alternative to selling power is "net metering or billing," where your system offsets the amount of power you purchase from a utility. Many states in the USA have net metering provisions, however, you will still have to negotiate with the utility concerning their interconnection requirements.

Other Considerations

Many other factors will determine whether developing the site is practical. Penstock routing and placement is important. You will need to inspect and clean the penstock intake regularly. Freezing weather, livestock, and vandals can damage exposed piping, but burying it may not be practical or cost-effective. The piping must have adequate support to keep it from breaking apart or moving under the weight and pressure of the water. The turbine/generator should be above the stream's flood stage. A power line from the generator could be expensive.

Determining Economic Feasibility

The process of accurately determining economic feasibility can be complex. One very simple method is to add up all the estimated costs of developing the site, and for operating and maintaining the system over the expected life of the turbine, and dividing this amount by the system capacity (in watts), giving you $/watt. You can compare this to the $/watt cost of power from some other source. If you are considering selling hydroelectricity to a utility, you should calculate a levelized life-cycle cost per kilowatt-hour (kWh) using standard discounting techniques, and compare that with the kWh price that the utility will pay you for the electricity. The cost per kWh is determined by dividing total life-cycle costs by the estimated amount of energy, in kWh, the system will produce over its operating life. For more information on project economic analysis, consult your local library or bookstore for books on microeconomics, project feasibility assessment, agricultural economics, or life-cycle cost analysis.

Conversion Factors

Here are some of the conversion factors you may need to assess your site's feasibility: 1 cubic foot (cf) = 7.48 gallons; 1 cubic foot per second (cfs) = 448.8 gallons per minute (gpm); 1 inch = 2.54 centimeters; 1 foot = 0.3048 meters; 1 meter = 3.28 feet; 1 cf = 0.028 cubic meters (cm); 1 cm = 35.3 cf; 1 gallon = 3.785 liters; 1 cf = 28.31 liters; 1 cfs = 1,698.7 liters per minute; 1 cubic meter per second (cm/s) = 15,842 gpm; 1 pound per square inch (psi) of pressure = 2.31 feet (head) of water; 1 pound (lb) = 0.454 kilograms (kg); 1 kg = 2.205 lbs; 1 kilowatt (kW) = 1.34 horsepower (hp); 1 hp = 746 Watts.

References

The references below provide additional information.

Some of the following publications are available in Adobe Acrobat PDF, Download Acrobat Reader.

Publications

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- "Induction Motors for Small-Scale Hydro," B. Haveland, (No. 71), Jun/Jul 1999, pp. 36-44.
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- "Rules for Surviving Micro Hydro Power," T. Kinzel and S. Kingsley, (No. 47) Jun/Jul 1995, pp. 16-21.
- "Self-Cleaning Hydro (intake) Screens," P. Geddes, (No. 71, Jun/Jul 1991, pp. 64-67.
- "Ultra-Low Head Hydro," C. MacLeod, (No. 23) Jun/Jul 1991, pp. 6-10.
- "Water Power in the Andes," R. Davis, (No. 71) Jun/Jul 1999, pp. 50-54.

How To Build and Operate Your Own Small Hydroelectric Plant, J. Butler, TAB Books, 1982. Out of print. This book contains a detailed description of a small-hydro system in Vermont and useful information on building a hydro system.

Hydroelectric Project Licensing Handbook (PDF 1.27 MB), *Hydroelectric Project Handbook For Filings Other Than Licenses And Exemptions* (PDF 100 KB), and *Report On Hydroelectric Licensing Policies, Procedures, And Regulations Comprehensive Review And Recommendations...* (PDF 592 KB), Federal Energy Regulatory Commission, 2001 See reference to FERC below.

Microhydropower Handbook,E & G Idaho, Inc., U.S. Department of Energy, 1983, (2 Vols.). Available from National Technical Information Service, Email: orders@ntis.gov. Vol 1, 428 pp. Order No. DE83006697; Vol. 2, 408 pp., Order No. DE83006698. This handbook contains detailed information on system design, construction, operation, economics, and legal and environmental issues.

Micro-Hydro Design Manual: A Guide to Small-Scale Water Power Schemes, A. Harvey, et al., Intermediate Technology Development Group, London, 1993. 288 pp. ISBN 185339-103-4. This manual covers design, operation and maintenance, commissioning, electrical power, induction generators, electronic controllers, management, and energy surveys.

Micro-Hydro Pelton Turbine Manual, J. Thake, Intermediate Technology Development Group, London, 1999. Out of print. 320 pp. ISBN 185339-460-2. This book provides information on how to manufacture Pelton turbines.

Micro Hydro Power Sourcebook, A. Inversin, National Rural Electric Cooperative Association (NRECA), 1986. Available from NRECA International Foundation. This manual thoroughly describes all aspects of micro-hydro system design and installation in a developing country context, but contains information applicable anywhere.

Motors as Generators for Micro-Hydro Power, N. Smith, Intermediate Technology Development Group, London, 1994. 84 pp., ISBN 185339-286-3. This is a guide to the use of induction motors for electricity generation.

Pumps as Turbines (2nd Ed.), A. Williams, Intermediate Technology Development Group, London, 2003. 84 pp. ISBN 185339-285-5. Available from Stylus Publishing (see Organizations below). This is a practical book for using standard water pumps as water turbines.

The Residential Hydro Power Book: The Complete How-to-Manual for DC Residential Hydroelectric Systems, K. Ritter, Sierra Solar Systems, 1996. 152 pp.