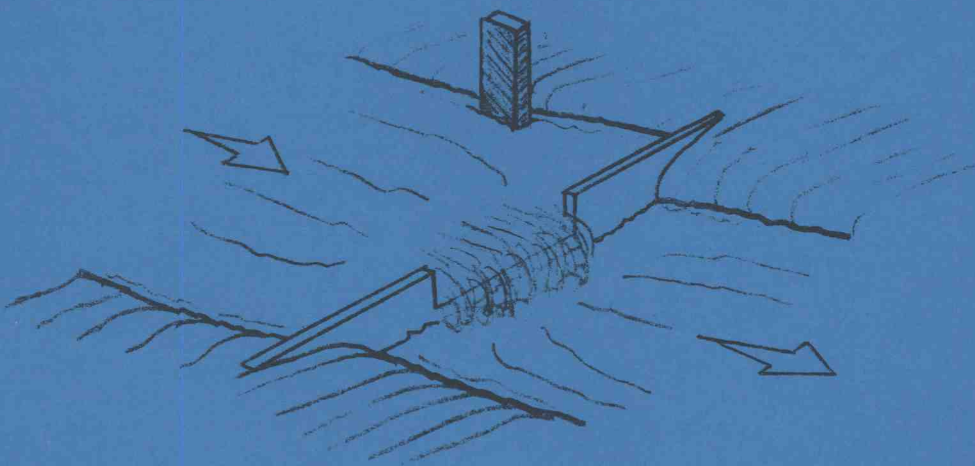
ASSESSING STREAM POTENTIAL FOR BACKYARD HYDROPOWER



BY

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What is Hydropower?

Hydropower is power produced by flowing water. It involves energy transfer from water to a spinning shaft. Hydropower systems have been used around the world for hundreds of years in mechanical systems to transfer shaft energy directly to nearby equipment. The first use of hydropower to generate electricity was in Appleton, Wisconsin, in 1882. In the 1900's most hydropower has been developed with electrical systems that send energy to markets far from the stream. Technological improvements and "economy of scale" have led to progressively bigger systems. Today, hydropower offers one of the least costly forms of energy development in the Pacific Northwest.

Many sites for hydropower development remain, but competition for water and land resources and adverse environmental impacts make future development of large sites unlikely. Recent interest in meeting energy needs has focused on smaller sites where impacts on other water uses and stream environments may be minimized.

This pamphlet focuses on the smallest systems--those that might provide electric energy for an individual residence, farm or ranch. Such systems are often referred to as micro, residential, homescale, or backyard hydropower and may have power outputs of only a few kilowatts.

How a Typical System Works

A hydropower system is built around a turbine and generator. A water turbine is a device rotated by moving water that converts this motion to mechanical energy at a rotating shaft. The energy can be used directly to operate nearby equipment or the shaft can be connected to a generator to produce electricity.

The typical system has several components. These are shown in Figure 1. Some systems may also have energy storage capabilities, typically a set of batteries or a water storage pond at the intake.

Some Terms and Performance Information

The power potentially available at a hydro site depends on the elevation drop or "head" and the rate of water flow or "discharge". Head is the total usable water elevation drop at the site. Discharge is the volume of water in

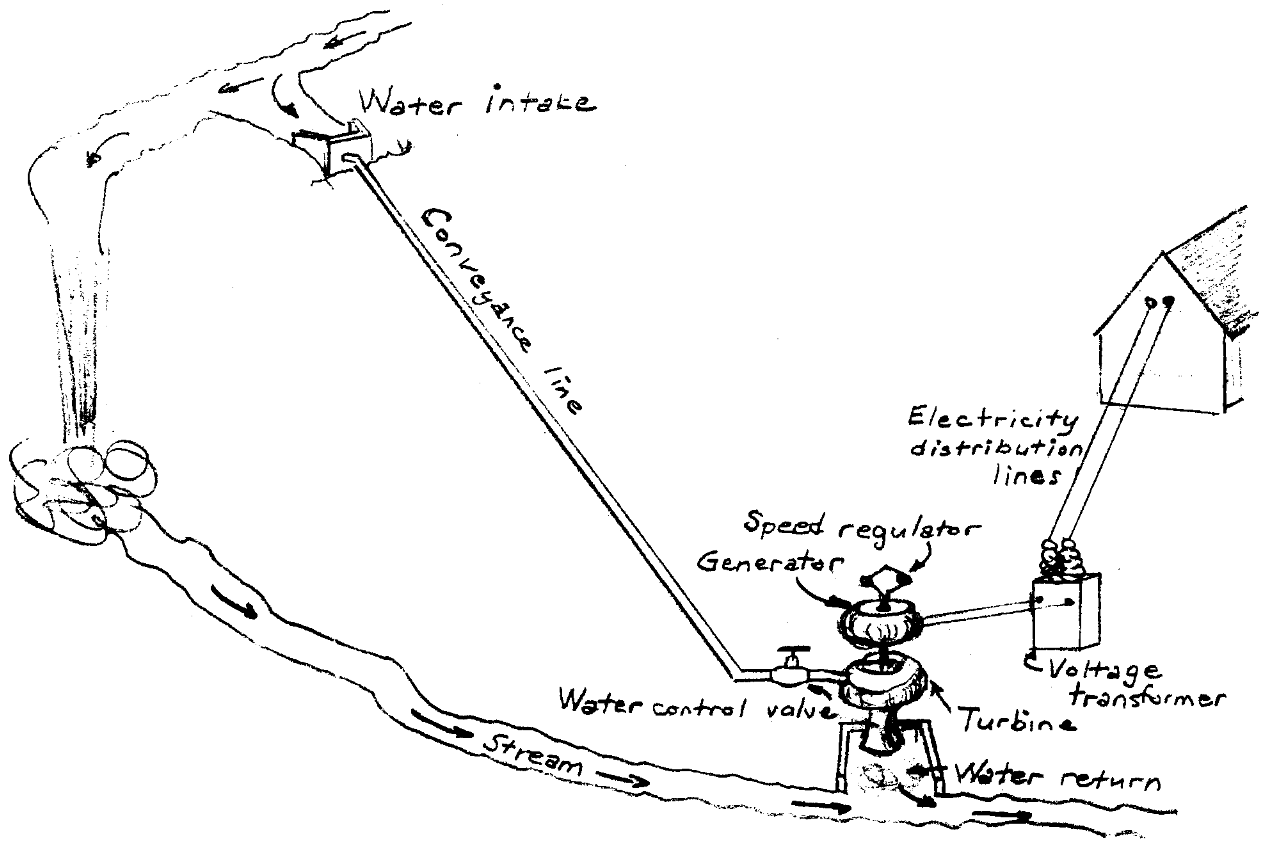


Figure 1. Components of a typical backyard hydropower system.

some time interval passing any given location. The same power can be produced from many combinations of head and discharge, since the two terms are multiplied together to calculate power. Thus, a high-head/low-flow site can produce the same power as a low-head/high-flow site. Equipment is often more costly in the latter case because it is likely to be larger.

Not all of the theoretical head available can be developed. Friction and losses at bends and valves occur in the piping system. These are collectively called head losses because they can be expressed in terms of the equivalent amount of head lost. Head losses increase with greater pipe length, increasing roughness of the pipe interior, increasing water velocities or decreasing pipe diameter. Piping that is short, smooth and of large diameter has less head loss than long, rough, small-diameter pipe. The net head available is determined by subtracting these head losses from the theoretical head available. Typical piping systems may lose 5 to 25 percent of the available head in compromising between higher pipe costs (larger pipe size to reduce head loss) and greater power output (more available head).

The theoretical power available must be adjusted downward because of friction, power conversion, and related losses in the turbine and generator. These losses vary with the equipment selected. The power and power losses also vary with the head and discharge available at the site at any instant, because flow rates are not constant. Efficiencies of 70 to 85+ percent are common for turbines. Efficiencies of large wooden water wheels range from 10 to 75 percent.

Turbine operating characteristics vary. Some turbines are designed for high efficiency at a specific head and flow or for a narrow range of head-flow combinations. For these, variations from design conditions result in appreciable reduction of efficiency. Other turbines are designed to provide good efficiency over a broad range of flows when heads are near the design head. Both categories of turbines can meet a wide range of power demands, but the second group generally is more efficient. Turbines with intermediate characteristics are also available.

Energy is equivalent to power multiplied by the time interval over which that power is applied. Thus, a plant working steadily at a 10-kilowatt power capacity for 1 hour will produce 10 kilowatt-hours of energy. If the same plant works for 1 hour at a reduced power of 2 kW it will only produce 2 kWh of energy. This can happen whenever the available discharge or head is less than designed-for values or whenever the demand for energy is less than that which can be produced by the machinery. Ideally, an automatic control system is used to adjust the energy output from the power station to match the demand at the other end of the power line. An interconnection with a power utility allows any excess supply of energy, compared to household demand, to be added to the utility's network.

Is Backyard Hydropower for You?

Lets now turn to the important question of whether a small stream offers the potential for development of a backyard hydropower system. Before that question can be answered satisfactorily, you will need to gather information, make some calculations, and talk to a few key people. This pamphlet offers some specific suggestions and guidelines for assessing the power you might be able to develop and the energy you need. This is critical information to know before you start spending money on equipment and construction.

Guidelines for Water Resource Assessment

Developing a residential-size hydropower system involves several important tasks. One of the first and most critical tasks is to assess the potential of the stream for providing the needed energy. Several steps are involved in making such a resource assessment. These are organized in the following paragraphs in the form of a set of guidelines.

Resource Assessment Steps

Seven steps are important in making a resource assessment to see if you have a promising site for hydroelectric development. These are:

1. site selection;
2. tentative system layout;
3. check on right to use water;
4. analysis of hydropower potential;
5. estimate of energy needed;
6. comparison of energy supply and demand; and
7. check on constraints on development.

You can carry out these steps with very little help from others. Most can be done within a day or two, but one will require follow-up work over a longer period to get representative streamflow information.

Site Selection

The first step in planning a residential hydropower system is to find a suitable site: a stream with running water and adjacent land on which to build the power station and all related facilities. These need to be reasonably close to the point of energy use unless you also plan to build a transmission line. If streamflow is abundant but the ground slope is rather flat, a low-head waterwheel turbine needing only 1 to 10 feet of head might be usable directly in the stream. If the streamflow is small and there is little head available the site may not provide enough power. Where the ground slope is greater or a small waterfall occurs, a larger in-stream water wheel might be usable or water might be diverted through a pipe to allow use of a more efficient type of turbine. The best site provides the greatest head in the shortest distance, as this allows you to develop a system with minimal piping and thus to limit the pipe costs and friction losses.

If you don't already own all of the site on which you want to build, one of the first actions taken after the resource assessment should be site acquisition. This might be done through outright purchase, lease, or easement, so that you have legal control over the land needed for your hydropower system.

Tentative System Layout

If you have some choices about where to put the water intake, turbine, and water return to the stream, it is now time to decide on a tentative system layout. You will want to achieve the greatest head with as little loss as possible. The intake should be placed where debris blockage is unlikely and where a fish screen can be installed if needed. The water return should let the used water re-enter the stream without causing bank erosion or other problems. The turbine should be low enough to give you the greatest possible head, yet high enough to let used water return to the stream and high enough to avoid being flooded during storms. A sketch or drawing with pertinent dimensions will be very useful. Later, in seeking a water right you need to describe the locations of water diversion, use and return. Therefore, it will be helpful if your drawing shows property lines or other reference points.

You may have more than one choice for siting the system. The head available, head lost, and water discharge may differ among the sites. Therefore, you may need to check more than one for feasibility.

Eventually, if the stream potential looks favorable, you will want to update the tentative system layout to reflect any changes made to eliminate constraints or to better meet any special permit requirements. If someone else will build the system for you, accurate maps or drawings will be needed. Even if you build it yourself, detailed drawings or stakes on the ground will be important so that you don't miscalculate the lengths for piping and other system elements.

Check on Right to Use Water

Another step is to verify that you will be able to obtain a right to use water for hydroelectric power. Either a permit of water right or a hydroelectric license will be required from the Oregon Water Resources Department. The permit or license grants the right to construct, operate, and maintain the project facilities and establishes legal right to the use of the water involved. All waters in Oregon belong to the public, are managed by the State, and may be appropriated for beneficial use through a "water rights" process. Anyone can file a water right claim but a seniority system ("first-in-time is first-in-right") applies and is enforced at times when water is scarce in comparison with the demands for water use. An ordinary water claim is perpetual whereas water use authorized by a power license is concurrent with the license period (e.g., 20 years for minor projects). The state licenses projects of all sizes. Federal licensing also can apply if non-federal projects (1) involve federal lands, (2) use water from a government dam, (3) affect interstate commerce (including private projects connected to any public utility system), or (4) are on a navigable waterway.

At the preliminary stage it is sufficient merely to verify the limits that may exist in obtaining a permit or license. For example, you will want to know if a short diversion-and-return system is possible or if all water must be left in the stream. This will govern your choices for power plant design. Later, if a residential hydrosystem still is promising, you will want to apply for a permit or license.

Analysis of Hydropower Potential

The next step is to estimate the power and energy available at the site. As already noted, you will need to determine the available head and the water discharge. In the calculations that follow, we have assumed that you will generally be measuring in feet, rather than with metric units. The conversions are simple:

1 foot	= 0.305 meter	3.28 feet	= 1 meter
1 square foot	= 0.0929 square meter	10.8 square feet	= 1 square meter
1 cubic foot	= 0.0283 cubic meter	35.3 cubic feet	= 1 cubic meter

There are three basic formulas to use: the discharge equation, the power equation, and the energy equation.

1. The discharge equation is $Q = (A) \times (V)$

   where Q = water discharge

   A = water cross-sectional area

   V = average water velocity.

Discharge is usually calculated in cubic feet per second or cubic meters per second, based on area in square feet or square meters and velocity in feet per second or meters per second, respectively. Occasionally, very small discharges are measured with a barrel and calculated in gallons per minute. The corresponding conversion factor is:

1 cubic foot per second = 449 gallons per minute

2. The power equation is $P = (C) \times (Q) \times (H_{net}) \times (e)$

where P = power

C = conversion factor that includes the unit weight of water

H_{net} = net available head at site

e = machinery efficiency expressed in decimal form.

Depending on the measurement system used the equation becomes:

$P_{horsepower} = (0.113) \times (Q) \times (H_{net}) \times (e)$ . . . foot system

or

$P_{kilowatts} = (0.0846) \times (Q) \times (H_{net}) \times (e)$ . . foot system

or

$P_{kilowatts} = (9.81) \times (Q) \times (H_{net}) \times (e)$ . . . metric system

In making conversions:

1 horsepower = 0.746 kilowatts
1.34 horsepower = 1 kilowatt

3. The energy equation is $E = (P) \times (\Delta T)$

where E = energy in kilowatt-hours

P = power in kilowatts

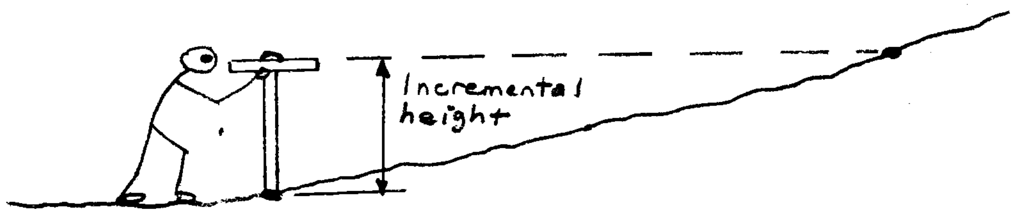
ΔT = time interval in hours during which power is used.

The application of these equations to assess the hydropower potential requires three types of field determinations: head, discharge at a particular time, and discharge variability over time. Then power and energy potentials can be determined.

Head. The theoretical head available can be estimated crudely or with great accuracy, depending on the equipment used and the time and care taken. Initially, only a rough estimate is needed; later, an accurate estimate will be needed.

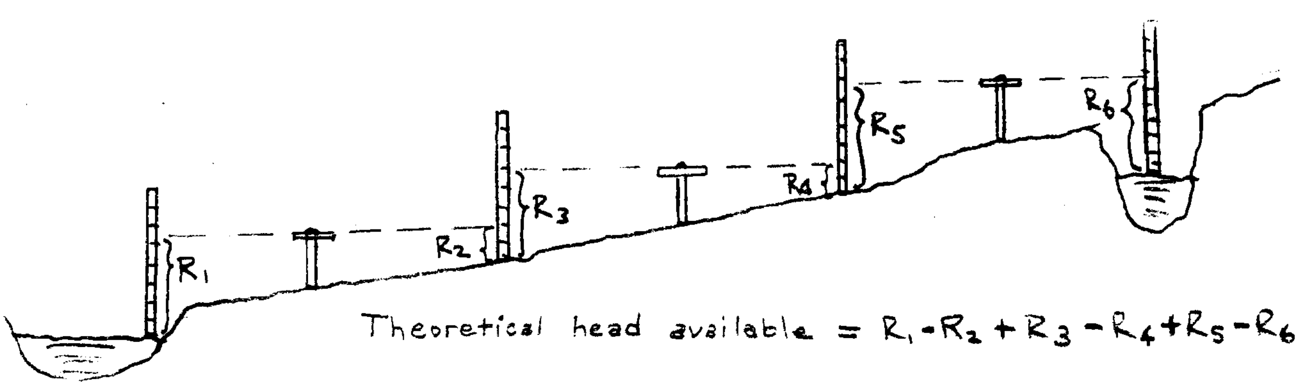
Rough estimates can be made by eye if you are a good judge of height or by using a topographic map if your site has a high head and is in an area where U.S. Geological Survey topographic maps have sufficiently detailed elevation contour lines.

A better technique, but still quick, is to use a carpenter's level and a 2" x 2" about 5 feet long to do some rough survey leveling between the water intake and return points for a potential site. (You can work in metric units if you prefer, using the conversion factors already given.) Use the 2" x 2" as a vertical stand to support the level in a horizontal position. Measure the height from top of level to bottom of 2" x 2" and use this as the incremental height for each sighting.



Start at the lower end of the route and sight horizontally along the level at some rock or other reference object along the route. It will be one increment of height above the starting point. Then move the 2" x 2" and level to the reference object, set it up there and sight along the level to find a new reference object along the horizontal line of sight. It will be an increment of height above the previous reference point. Repeat this as often as needed to reach the upper end of the route. If the last horizontal line of sight is above the water at the proposed intake, sight at some object near the water and subtract its height above water from the full height increment for your line of sight. Then add up all incremental heights (including the adjusted final increment) to get the estimated theoretical head.

When an improved estimate of available head is needed later, the same technique can be used with sights made at an improvised level rod (for example, a 1" x 2" 5 to 8 feet long and marked in feet and inches or tenths). This will allow shorter, more reliable sights, since the rod can be read more accurately, avoiding the long horizontal lines of sight to the points of intersection with

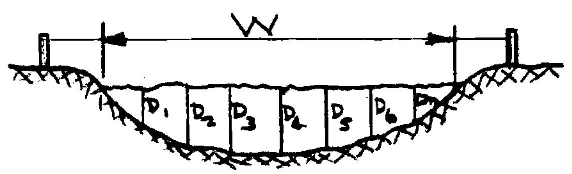


the rising ground. The level and level rod are moved alternately. Two people are needed. Still better estimates can be obtained by use of a surveyor's level (or transit) and leveling rod.

For purposes of a preliminary estimate of head, the piping losses might be estimated arbitrarily at 10 to 25 percent of the theoretical head. Thus, the net head used in the equation may be estimated as 75 to 90 percent of the theoretical head available.

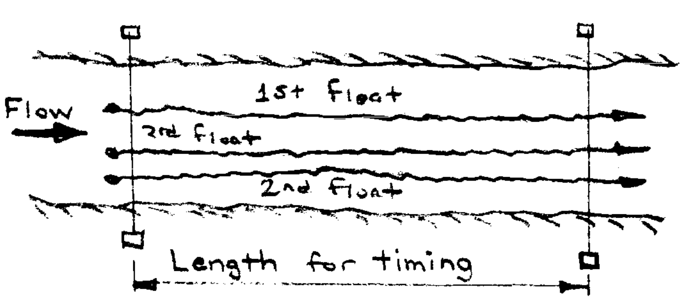
<u>Discharge at a Particular Time</u>. The discharge at any particular time can be estimated roughly by means of a stopwatch, tape measure, something that floats (twigs, etc.), and a long stick. These allow rough estimates of the water velocity and cross-sectional area.

Find a fairly straight stretch of the stream with fairly uniform width and depth. Pick a typical cross section and measure the water width with the tape measure. Use the long stick like a ruler to estimate the depth at each foot across the stream. Average these depths to estimate the average stream depth. Multiply this depth by the stream width to estimate the cross-sectional area. Next, measure along the stream for a length of 20 or more feet and mark off the start and finish lines for a float "race course". Throw the float in just above the start line several times, each time at a different fraction of the distance across the stream. Time its travel between markers. Use the average time and the measured distance to calculate the average velocity (distance in feet divided by time in seconds). Finally, use the discharge equation with the estimated area and velocity to get flow rate.



$$D_{avg.} = \frac{0 + D_1 + D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + 0}{9}$$

$$A = D_{avg.} \times W$$



$$T_{avg} = \frac{T_1 + T_2 + T_3}{3}$$

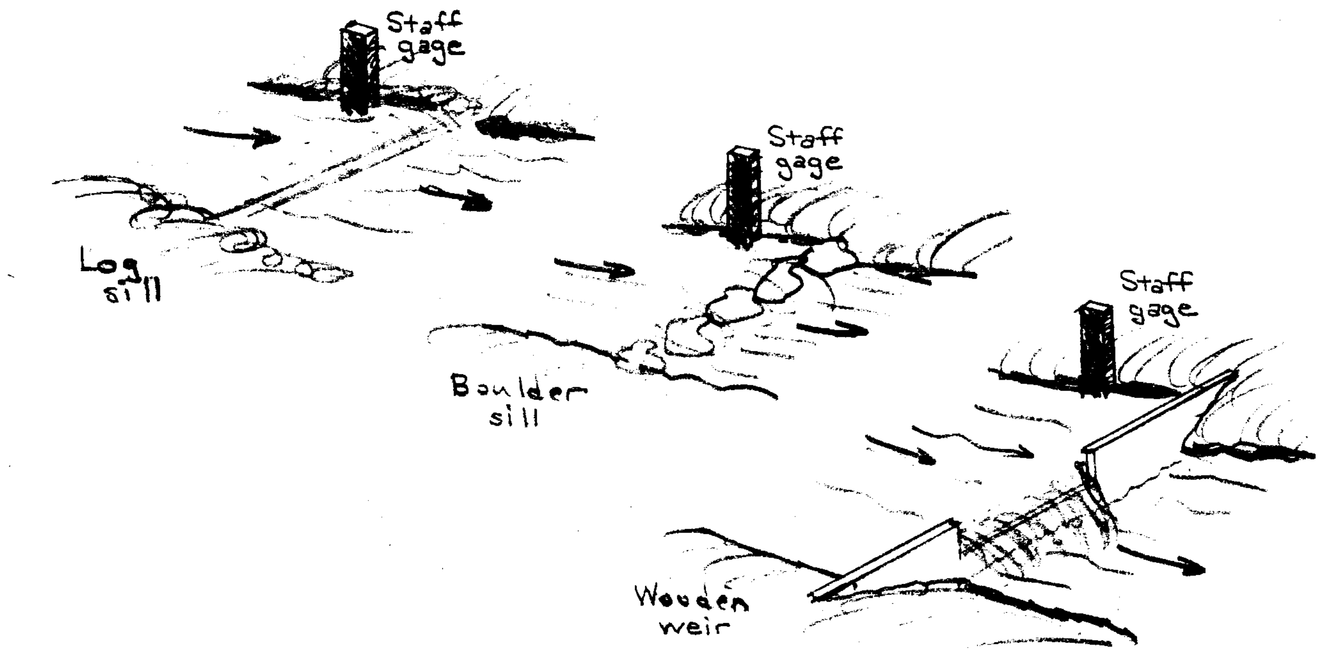
$$V_{avg} = \frac{L}{T_{avg}}$$

$$Q = A \times V_{avg}$$

If the discharge is small and there is a local drop in the water surface in the channel (spill over a small water fall, down some rocks or over a log), you may be able to use a bucket or barrel and stopwatch to measure the discharge quite simply. The volume of the container should be determined. Then the length of time required to fill the container with the streamflow should be measured. Dividing the container volume by the filling time gives the discharge rate.

Discharge Variability over Time. Stream discharge varies with the weather and the season. For power production, the minimum flows likely at different times of year must be known. You may need all the water you can get from the stream during the dry season. The large flows are also of concern. You might need only a part of the streamflow for power production during times of storm runoff. But you will still need some idea of the magnitude of storm runoff so that you can protect your system from flood damage. Therefore, discharge estimates must be made several times over the year to determine its variability. Remember that both the area and the velocity change with discharge rate, so that more than water depth must be known for different times of year. For a rough estimate, a few discharge measurements may suffice.

To improve your estimate, you may want to build a small weir across the stream to simplify the task of estimating discharges at different times. You



may need permission to install this, if it is very substantial. The weir will allow you to develop a simple relationship between the water level at a staff gage (calibrated vertical post) placed a few feet upstream and the corresponding discharge in the stream. This relation is called a "rating curve". Once the curve has been established with a few discharge measurements, you will be able to dispense with those measurements and will only need to read the water level at the staff gage (unless larger or smaller flows occur than shown on the rating curve, in which case additional discharge measurements will be needed to extend the rating curve). The weir itself can be quite simple - a log or row of large boulders across the stream that will provide a stable low sill over which the water must flow and which backs up the water a few inches on the upstream side.

Power. The power available can be estimated from the measured head and discharge and the power equation. Because storm runoff is usually brief, it is better to make estimates using seasonal low-flow discharges rather than storm discharges. This keeps you from being overly optimistic about the power potential. When using the power equation an efficiency must be estimated. Since you have not yet picked the particular equipment to produce power, a cautious estimate - such as 50 percent - is reasonable. You can refine this later if the site looks feasible for development.

Energy. If you know or can guess the streamflow rates for different times of year, you can apply these for the appropriate time intervals to estimate the energy available for the corresponding period, using the energy equation.

Some checking of newspapers and weather sources will help you decide if your measurements are for a typical or non-typical period and will give you some idea of changes that might be expected from year to year (some local Chambers of Commerce have such data for their communities).

Example Calculations. Example calculations for head, discharge, and the energy assessment are appended so you can see how the above steps are combined.

Estimate of Energy Needed

You will want to make your own estimate of your energy needs. The easiest way to do this is to use the energy value listed on your utility bill. But the average includes night-time hours when very little energy is used as well as critical times (breakfast, dinner, early evening, house cleaning and laundry times) when energy is rapidly consumed. Therefore, you will still need to estimate your daily and weekly cycles of energy use.

The easiest way to reliably estimate your daily and weekly energy needs is to make some spot surveys of your present energy use at several different times of day over a week or more. You might mark a sheet of paper with the 24 hours of the day along one side and the 7 days of the week along the top. Leave some room at the bottom to summarize the power ratings for your major electrical appliances. Then, go around your home frequently (e.g., every hour on the hour during waking hours) and add up the power ratings of all items that are on at that instant. You will quickly discover how your energy needs vary over time and what your peak energy demands are. As a check, you can project your energy use over a full month and compare the total kilowatt-hours of energy consumed with your utility bill.

Examples of Typical Household Appliance Loads

Appliance	Power	Monthly energy consumption
Kitchen	Watts	Kilowatt-hours
Range	8,500-16,500	100
Refrigerator	200-600	60
Toaster	550-1,170	4
Coffee maker	600-900	10
Skillet	1,250	30
Blender	600	2
Fan	250	8
Utility room		
Water heater	1,200-7,000	350
Washing machine	250-640	6
Clothes drier	1,600-5,000	80
General house areas		
Lights	Vary widely	
House heating	10,000-150,000	2,000
Electric blanket	200	16
Iron	400-1,100	8
Food freezer	300-800	90
Hi-Fi (solid state)	30	4
Television	200-315	40
Radio (solid state)	50	6
Sewing machine	30-100	2
Vacuum cleaner	200-1,000	2
Clock	1-10	3
Hair dryer (hand-held)	400	2

Note: More current and power are used to start most motors than to keep them running steadily.

Comparison of Energy Supply and Demand

Your energy system must provide for your peak load, not just your average load. If your stream provides adequate hydroelectric energy, your system can be kept simple. If there is not enough stream energy available, you will need an energy storage system (an intake reservoir or storage batteries), a backup power system, connection with a local power utility line, or a change of consumption pattern if you are to avoid having "brownouts". Hence, comparison of energy supply from the stream and energy demand for your use will have an important bearing on your final system components, including decisions regarding supplemental power sources and energy storage systems.

Check on Constraints on Development

There may be environmental, fishery, navigation or other problems associated with developing your scheme. These may involve neighbors or others along the stream who may be affected by construction or operation of your system. Poor geological conditions or erodible soils may be present. Plant and animal life may be limiting factors. Some of the potential problems will become apparent after looking over the site. The Oregon Department of Fish and Wildlife can help identify potential environmental problems.

Discovering potential development problems as early as possible can save time and trouble later. You can modify your plans or take preventative steps. If you are developing hydropower, you are involved on a small scale with the same problems as utilities and federal agencies that build large power plants. You have a responsibility to avoid environmental damage or harm to other water users.

Your check to identify any likely constraints on development should be supplemented by definite information on what you can or cannot do. For example, how much water must be left in the stream (minimum in-stream flow)? Is fish screening required? Will downstream neighbors complain if you develop any short-term (night-to-day or day-to-day during the week) water storage at your intake? You should also make definite plans on how to avoid potential problems. Any problem that cannot be resolved at this point will probably call for alterations in your system layout and plan of operation.

After the Resource Assessment, What Next?

By now you should have a fair idea of whether to pursue or give up developing your own hydropower. You now know whether a suitable site exists, if you will be entitled to use the water, and whether the energy available can meet your needs. If development still is promising, you will want to consider several additional steps. These are briefly discussed below to indicate what is involved. However, it is not our intention to provide detailed guidance on these in this pamphlet. You may be able to handle some of these steps alone but may require the help of a specialist for other steps. Remember, as you proceed, that we are talking about small residential hydropower; bigger sites require a much more extensive analysis than suggested here.

Review of Layout and Hydropower Assessment

A definite alinement for your system should be selected. The total available head should be remeasured and adjusted accordingly. Additional streamflow data may be needed. The power and energy calculations should be refined as new or better data permit.

Application for Water Right and any Needed Licenses

It is now time to contact the Water Resources Department to obtain and fill out the necessary forms for a water permit or license. Based on your specific plans, they will advise you of the appropriate forms needed. There will be modest fees involved when you submit the completed documents. But you will still be able to drop all plans for hydropower development later if you change your mind.

Detailed Design

Design includes the layout and sizing of the components involved. You will want to select the lengths and diameters for the piping, decide where to put valves, and what size valves to use. Design also includes the choice and detailing of all structural parts of the system: intake, outlet, turbine foundation, walls and roof. Erosion protection, debris and fish screening, flow bypassing/diversion all must be included at this point. You will be able to get many ideas and helpful information from various articles and advertising literature showing other people's systems. Visits to people who have backyard hydrosystems will be particularly helpful, since they have already faced the problems you are now dealing with.

You are also ready to contact equipment suppliers. The data you have already compiled will help them identify the type of turbine-generator that best meets your needs. If they are nearby, they may be willing to visit your site for a first-hand look. Many are too far away to make a visit unless you are willing to reimburse their time and travel expenses. Some suppliers are more knowledgeable than others. Be sure to check to find a qualified supplier. The supplier also may be able to advise you on special development problems. Past experience with difficulties can help pinpoint poor designs and save you potential headaches.

If you are contemplating any type of dam, there are several cautions: (a) construction of a dam is a highly technical undertaking; (b) special state laws apply to dams; (c) you must own or control all flooded land; (d) in the event of dam failure, you will be liable for all damages. A professional engineer can advise you on construction of a safe dam for your site. Consult the Water Resources Department regarding applicable laws.

Cost Analysis

Once your design is complete you will be able to estimate the costs of building the system. It will be helpful to collect literature and reference material to give an idea of the likely costs. You will need literature on turbines, generators, control equipment, energy storage, piping, and valves. A trip to the local hardware store can give you an idea of some costs. Phone calls may be needed to get estimates for other items. Estimate the amount of lumber and concrete needed and the costs involved.

Financing Analysis

The next step is to determine the ways in which you can finance the costs of construction, equipment purchase, installations, subsequent operation-maintenance-repair-replacement, any additional insurance, etc. There are some tax credits and other incentives that will offset these costs so that the project may not be as costly in the long run even if initial costs look high.

The present income tax laws allow sizeable tax credits for installing energy conservation measures. For instance, if your project takes more than one tax year you will want to find out whether the tax credit is available each year (if so, construction in stages may be advantageous). Other federal or state incentives are available, with new ones being considered each year.

Checking on currently available incentives may help you find ways to finance your power station. One such incentive that seems very attractive is that utilities are required by federal legislation to purchase power from small power producers. Complementary Oregon legislation passed in 1979 requires utilities to purchase excess energy at rates which do not unfairly burden other customers of the utility. Hence, you might be able to sell any surplus energy to a utility if you presently have power lines or plan to install them (this latter would then be an added cost in your evaluation).

A Final Review

You are almost ready for the big decision. First, review the alternatives available for meeting your energy needs. Remember, a private hydropower station is only one of several available options. While it gives you freedom to produce your own energy, your use of a stream implies that you accept responsibility for maintaining the good "health" of that stream and for protecting others against potential damage that could result from your development. You must comply with applicable federal and state laws. Also, working in water adds complications not encountered with dry-land construction.

If there is any doubt in your mind, wait before you develop the site. Remember, your water right application has a generous timespan within which to complete the project. Meanwhile, resolve these doubts. A qualified professional engineer or builder with experience in developing small hydropower systems can be of very great help at this point.

Now you are ready for the BIG decision - whether or not to develop your own residential hydropower system. Regardless of your choice, we hope that this resource assessment was useful in helping you make a sound decision.

Useful Addresses and Telephone Numbers

Oregon Water Resources Department
Mill Creek Office Park
555 13th Street NE
Salem, Oregon 97310
(503) 378-3739

Oregon Department of Fish & Wildlife
506 SW Mill Street
Portland, Oregon 97201
(503) 229-5403

Oregon Department of Energy
102 Labor & Industries Building
Capitol Mall
Salem, Oregon 97310
(503) 378-4040

Some Useful References

"Waterpower for your Home"; Popular Science; E.F. Lindsley; May 1977; pp. 87-93.

Micro-hydro Power: Reviewing an Old Concept; U.S. Dept. of Energy, Idaho Operations Office; Idaho Falls, Report DOE/ET/01752-1; Prepared by the National Center for Appropriate Technology; January 1, 1979; 60 pp.

Micro-hydro; A Bibliography; Beth Moore; Idaho Water Resources Research Institute; University of Idaho; Moscow; May 1979; 19 pp.; $1.50.

Hydroelectric Projects in Oregon; Oregon Dept. of Water Resources; Salem; undated (1979); 5 pp.

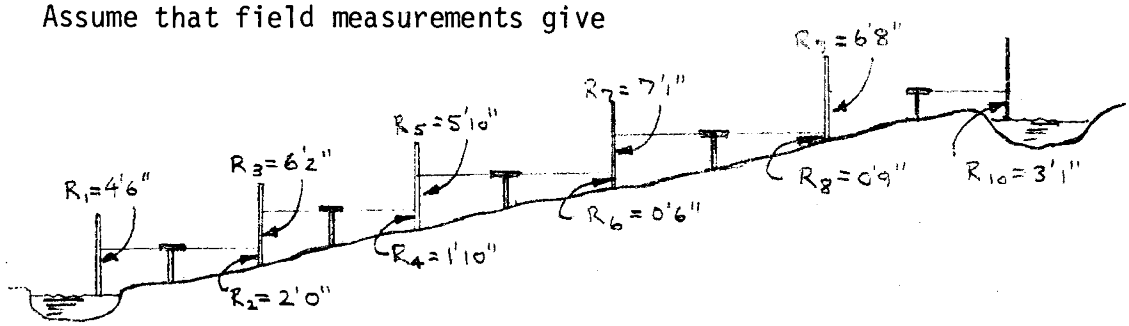
Oregon Residential Alternate Energy System Tax Credit Packet - Hydro; Oregon Dept. of Energy, Salem; November 1979; 15 pp.

Hydro Task Force Final Report to the Oregon Alternate Energy Development Commission; June, 1980; 61 pp. (Available through Oregon Dept. of Energy, Salem).

An Example of Head and Discharge Calculations

Theoretical head available:

a) Assume that field measurements give



b) Therefore

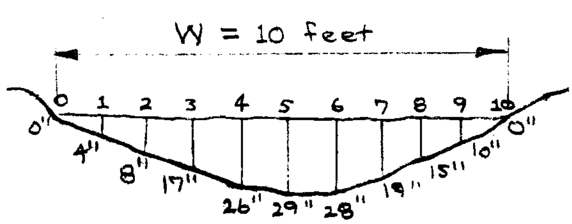
Theoretical head available = (4'6" + 6'2" + 5'10" + 7'1" + 6'8") - (2'0" + 1'10" + 0'6" + 0'9" + 3'1")

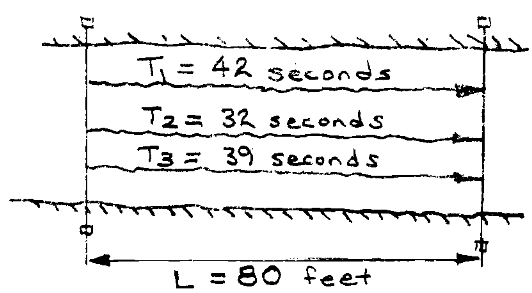
= (28'27") - (6'26") = (30'3") - (8'2")

= 22'1"

Discharge at a particular time:

a) Assume that field measurements give





b) Therefore

$$D_{avg} = \frac{0 + 4 + 8 + 17 + 26 + 29 + 28 + 19 + 15 + 10 + 0}{11} = \frac{156 \text{ inches}}{11}$$

$$= 14.2 \text{ inches} = 1.18 \text{ feet}$$

$$A = D_{avg} \times W = 1.18 \times 10 = 11.8 \text{ square feet}$$

$$T_{avg} = \frac{42 + 32 + 39}{3} = \frac{113 \text{ seconds}}{3} = 37.7 \text{ seconds}$$

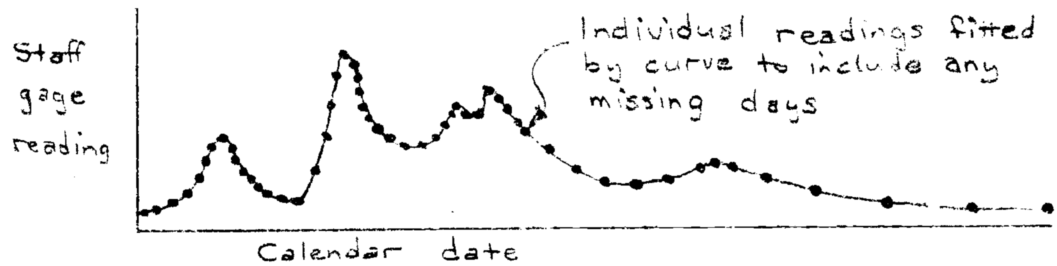
$$V_{avg} = \frac{L}{T_{avg}} = \frac{80 \text{ feet}}{37.7 \text{ seconds}} = 2.12 \text{ feet per second}$$

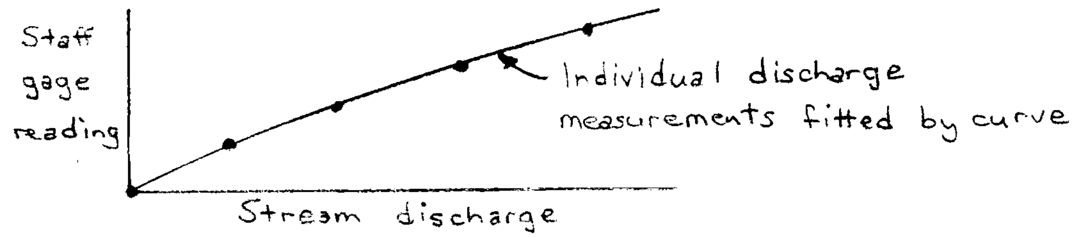
$$Q = A \times V_{avg} = (1.18 \text{ square feet}) \times (2.12 \text{ feet per second})$$

$$= 2.51 \text{ cubic feet per second or } 1125 \text{ gallons per minute}$$

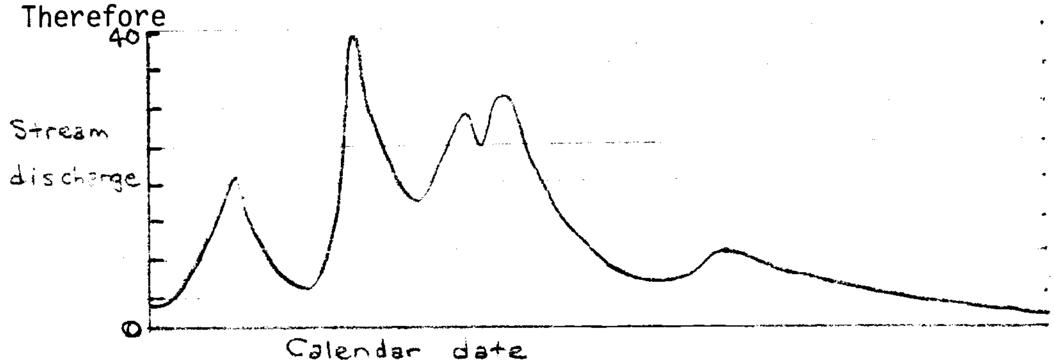
Discharges over time:

a) Assume that field measurements give

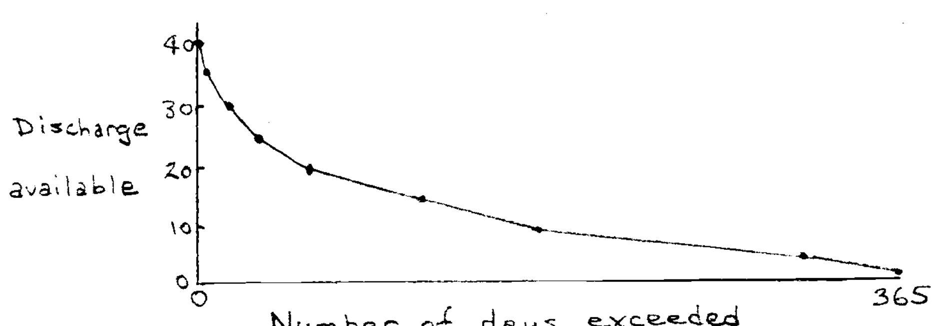




b) Therefore



Discharge range	Number of days flow is within range	Number of days flow exceeds minimum value in range
40-36	3	3
35-31	10	13
30-26	17	30
25-21	30	60
20-16	55	115
15-11	68	183
10-6	135	318
5-1	47	365



An Example Energy Assessment

Given:

1. Theoretical head available:

From surveying, diversion point elevation	=	57 feet	(summer level)
From surveying, return point elevation	=	- 0	(summer level)
Theoretical site head available	=	57 feet	(summer level)
Allowance for turbine height above water	=	- 5	(summer level)
Theoretical head available	=	52 feet	(summer level)

2. Streamflow available, based on several measurements:

Flow rate in cubic feet per second	Annual number of days flow exceeded shown rate
0.1	365
1.0	182
3.0	90
6.0	60
12.0	30

3. Selected design flow:

The system must work at full capacity at least 3 months (90 days) of the year. Therefore, design flow = $Q_{90\ day}$ = 3.0 cfs.

4. Length of pipeline:

Length from diversion point to turbine = 200 feet.

5. Pipeline friction losses:

From manufacturer's chart, friction losses for smooth pipe at the discharge matching your design flow of 3.0 cfs are as follows:

Pipe diameter in inches	Head loss in feet per 100 feet of pipe, at 3 cubic feet per second flow rate
2	2,645*
3	348*
4	83*
6	11*
8	3*

* Fictitious values

Determine:

1. Pipe size and net head:

   From the friction loss table, a 6-inch diameter pipe appears to be a good compromise between head loss (which decreases as size increases) and pipe cost (not shown but increases as size increases).

   For the 6-inch pipe, the net head (ignoring non-friction losses) is

   $$\begin{aligned}\text{Net head} &= \text{Theoretical head available - total friction loss}\\ &= 52 \text{ feet} - (200 \text{ feet}) \times (11 \text{ feet}/100 \text{ feet}) = 52 - 22\\ &= 30 \text{ feet.}\end{aligned}$$

2. Power available at design conditions:

   Assume initially a machinery efficiency of 50 percent (which is probably an underestimate at design flows but realistic for smaller flows):

   $$\begin{aligned}P_{90} \text{ days} &= 0.0846 \times (Q) \times (H_{net}) \times (e)\\ &= 0.0846 \times (3.0) \times (30) \times (0.50) = 3.8 \text{ kilowatts.}\end{aligned}$$

   This looks reasonable compared to typical household power demands.

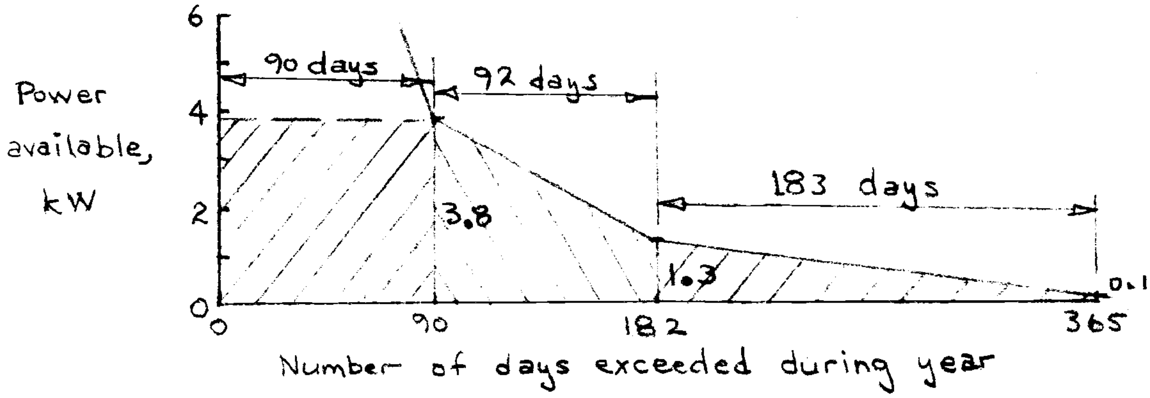
3. Power available at other times:

   Next, see what power can be produced with this system at lower flows

   $$\left.\begin{aligned}P_{182} &= 0.0846 \times (1.0) \times (30) \times (0.50) = 1.3 \text{ kW}\\ P_{365} &= 0.0846 \times (0.1) \times (30) \times (0.50) = 0.1 \text{ kW.}\end{aligned}\right\}\text{ Note that efficiency will vary with H and Q.}$$

   According to these calculations, during much of the year there is not enough streamflow to provide typical power demands. Hence, some type of energy storage or supplemental power will be required.

4. Annual energy potential for the system:



$$E = \Sigma P \times \Delta T = 3.8 \text{ kW} \times 90 \text{ days} \times 24 \text{ hr/day}$$

$$+ \left(\frac{3.8 + 13}{2}\right) \text{kW} \times 92 \text{ days} \times 24 \text{ hr/day}$$

$$+ \left(\frac{0.1 + 1.3}{2}\right) + \text{ kW} \times 183 \text{ days} \times 24 \text{ hr/day}$$

$$= 8208 + 5630 + 3074$$

$$= 16{,}913 \text{ kWh per year.}$$

For comparison, if peak power demand is 3.8 kilowatts and average power demand is 1 kilowatt, then

$$E = P_{avg} \times \Delta T = 1.0 \text{ kW} \times 365 \text{ days} \times 24 \text{ hr/day} = 8{,}760 \text{ kWh per year.}$$

Comments:

It looks like this system can provide energy needs much of the time if some type of storage is provided to meet peak demands. If connected to a power utility, the system should be able to produce more energy than is needed at the site, allowing some revenue to help pay for the cost of installation.