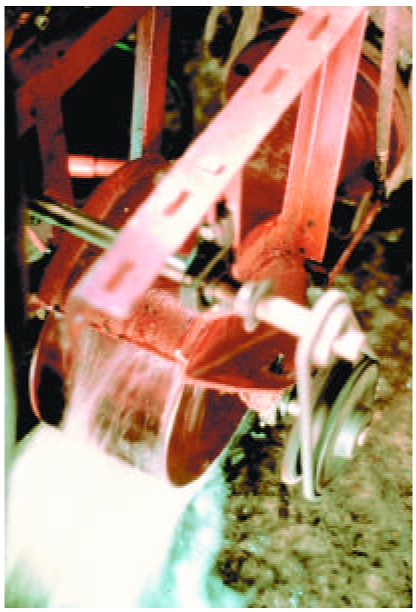
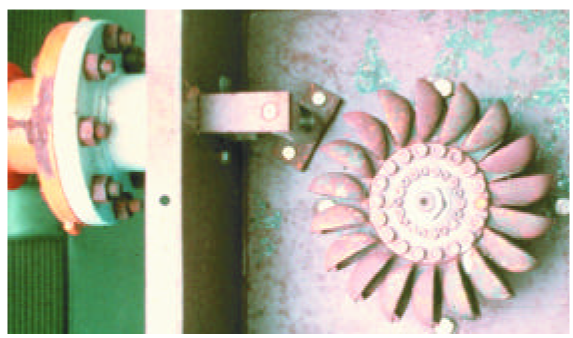
Do-it-Yourself Hydro Survey

Assess your site's potential for water-generated power

By Michael Hackleman





Does water flow across your land? Seasonally? Year-round? Right after a storm? How far does it drop in elevation across your land? How big is the flow? A big drop with a small flow, a small drop with a big flow, or, blessings from heaven, a big drop and a big flow— these sites are candidates for a hydro-electric system. And you can, inexpensively and with the help of a friend, find out if your site qualifies.

Water as energy

The beauty of free-flowing water is that it's a natural energy source. Even if you don't have a year-round stream, water energy could be available to you as a power source during the winter or rainy months. This is perfect for owner-builder systems that also use PV (solar-electric) modules since they partner each other through the year. When the sun wanes in the winter, the water flows. The bulk of energy production shifts easily from solar to hydroelectric in the winter and back to solar-electric in the summer.

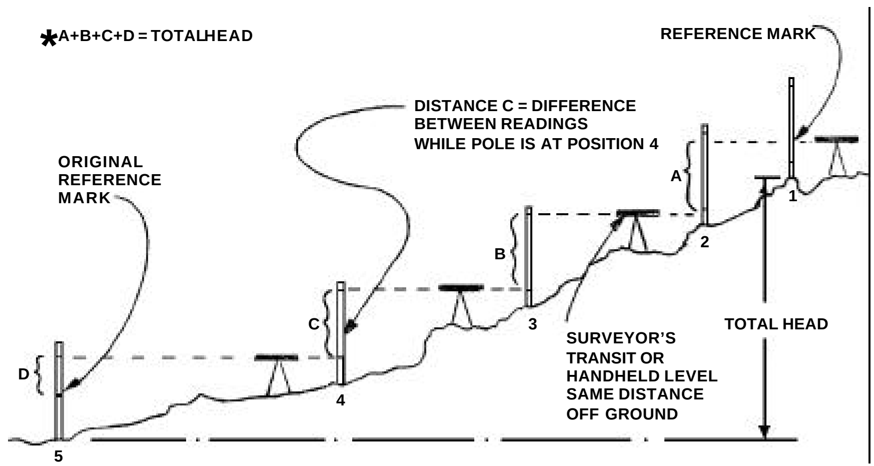
A recent application for hydro-electric systems is in erosion control. Many counties have programs that will help farmers, ranchers, and landowners mitigate erosion problems, particularly in watersheds and critical fish-spawning areas. As much as 50% of the costs incurred in applying one or more of several methods, i.e., rocks, gravel, stream diversion, and anti-erosion hardware on your land might be possible. A good design of hydro-electric system might qualify to handle this problem as a form of stream diversion. Most importantly, it does something constructively with the water's energy as it exits the system.

Up front, it's important to understand that the basic components of an independent energy system are more similar than different. That is, hardware such as a battery bank, an inverter, and monitoring equipment are virtually the same in any system.

Better yet, these components may be shared by hardware that taps the energy of solar, wind, and water simultaneously. The output of PV modules, wind-electric machines, and hydro-turbines and their control boxes will interface without difficulty or interference with one another. With the right balance, a system which is able to take energy from two or more

(Left, counterclockwise) An overshot-type waterwheel, a Banki-Mitchell turbine, and a Pelton wheel are popular choices for small-scale hydro systems.

(Right) The transit-pole method will find elevation changes.



sources (a hybrid) generally will prove less expensive than buying a standby generator with its attendant costs to run, repair, and maintain. This is a big plus.

The physics of water

Water has weight. Basic physics says, if it falls or flows downward, gradually or quickly, water gains momentum and expends energy. If we direct some or all of the same water through a pipe and a hydro-electric unit, electricity can be generated from the water's energy. This does not involve building a dam and installing big machinery. The average small-scale, 500 to 1000-watt hydro-electric unit uses 2-inch plastic pipe from a convenient point upstream to bring water to the hydro-electric unit mounted downstream. In climates with few freezes or little snow, the pipe lies atop the ground and it's easy to drain the system during freezes, restarting it later.

How much power?

A small-scale, Pelton-type hydro-electric unit weighs less than 20 pounds with its control box. It packs a big punch, though. A wind-electric machine must have a propeller diameter of 10-15 feet to capture enough wind (moving air) to generate 1kw (one kilowatt, or 1000 watts) of energy. Water is 680 times denser than air. For this reason, a 1kw water-turbine has an impeller that may only be 3-6 inches in diameter and spins at high rpm.

Many sites will not have enough fall and flow to generate 1000 watts of power. No matter. Even if you only net 50 watts of power from a hydro-electric system, it may be worth going after. Water power is generated through an entire 24-hour period. At a rate of only 50 watts, a microturbine will produce 1,200 watt-hours (1.2kWh) daily. This is equivalent to the output of four 50-watt solar modules exposed to six hours of sunshine.

There's a formula that will help you estimate what kind of power you might expect from water dropping a specific distance with a certain volume:

$$\mathbf{P = \frac{head \times flow}{9}}$$

Where:

P = power in watts
Head = vertical feet between intake and outlet
Flow = water flow in gpm
9 = conversion factor

You have to plug in the numbers to get an answer but—you have to *know* the numbers first. How do you find the fall and flow of water over your land, particularly if steep terrain or brush exists? Let's start with head.

Know your head

Head is the measure of the difference between the highest and lowest points in a water system in feet. Head represents only the vertical (not horizontal) distance between these points.

To find the head, you must use one of a variety of techniques for finding changes in elevation.

Previously, I've used surveying equipment and even a homebuilt transit and pole to find elevation changes over the length of a streambed (see drawing). This time-honored method involves two pieces of equipment: a measuring pole (downstream) and a transit (upstream). The leveled transit is used to sight horizontally, spotting and recording the reading on the measuring pole. Subtracting the height of the transit, the resultant number represents the measured vertical distance between the two points. After the reading, the transit is moved to the pole's former location and the pole is moved downstream. This process is repeated for as long as it takes to cover the whole distance. Adding up the numbers gives you the total value of vertical drop, or head over the portion of the stream that is measured.

The newest method I've tried is the hose-and-gauge method. John Takes taught me the basics of this method, which involves a simple hydraulic trick to find the drop in elevation. Water standing in a vertical or angled pipe creates pressure at the lower end. The value of pressure is not related to the weight of the water or the pipe diameter. Instead, it is a measured 0.433 psi (pounds per square inch) for each foot of vertical height of water in a tube or any container.

In the field, the rule is 2.3 vertical feet equals 1 psi. This is useful for calculations or when converting head into psi, or viceversa. Remember, it is only the vertical component of water in a pipe that creates pressure and produces a reading. It doesn't matter if the pipe is tilted, even at a 10°, 30°, or 60° angle.

So, if you install a pressure gauge at the end of a pipe that is filled with water and sloped down a hill, the pressure reading on it can be used to find the head. For example, suppose the pressure gauge reads 25 psi. Since 1 psi equals 2.3 feet of head, the reading of 25 psi demonstrates a head of 57.5 feet (25 psi x 2.3 ft/psi).

Now, let's substitute a garden hose for the pipe in our example. Install a pressure gauge at one end, fill the hose with water, and stretch it out over the ground with the open end up an incline. What's the pressure reading? Again, multiple the reading on the gauge by 2.3 ft/psi to find the head. This is the difference in vertical height between the top and bottom of water in the hose.

The trick in applying this knowledge as a method of surveying for hydro-electric potential is to take your readings over the length of the stream in discrete increments equal in length to the hose you use. When finished, the pressure readings may be added together and the total multiplied by 2.3 ft/psi to find the head.

Actually, you may take the readings along *any* path you choose between the intake (where the water is taken from the streambed) and the outlet, the site where the hydro-unit will generate the power and discharge the water from the system. That's because the hydraulic trick works regardless of the length of the hose you use, or the method you use to get down the hill. However directly or indirectly you conduct the survey, the psi readings and calculated head will total to the same values.

Assemble the parts

The hose-and-gauge method of finding the head involves a length of hose, a pressure gauge, and miscellaneous hardware.

In practice, a 100-ft water hose is good for a stream with easy access and not much drop over the land. A 50-ft or 75-foot hose will work better through brush and steeper slopes. You'll want to take a pencil and notebook to build a table. For each increment, record the number of the reading and the reading itself. For example, the entry, 6-14.5, might signify the 6th reading is 14.5 psi.

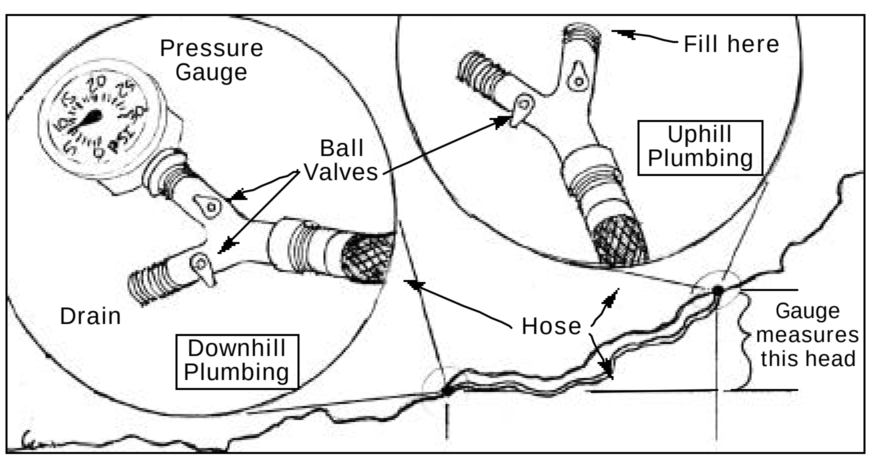
One additional benefit in the hose-and-gauge method of surveying is that it may provide you with another vital number: the length of pipe used in the hydro-system. If you are able to walk the most direct route between intake and outlet, your readings will yield both psi values *and* the length of pipe needed to cover that route. For example, if you use a 50-foot hose, the 6th reading you take is 300-feet (6 x 50 ft) away from the start point, top or bottom. So, the number of readings multiplied by the length of hose equals the shortest distance between the inlet and outlet of the system. Knowing the length of pipe your system will need will help you estimate its cost in advance.

The pressure gauge you use is important. If you hang a 50-foot, water-filled hose vertically, the maximum pressure reading possible is about 22 psi (50 ft. x .433 psi = 21.65 psi). In a 100-foot hose, it's 43.3 psi. The gauge you select should not be rated much higher than these values. The accuracy of gauges is best in the middle of their ranges. How accurate a reading of 10 psi will you find on a gauge that reads 0-150 psi versus a gauge that reads 0-25 psi? The best results come from picking the right length of hose with the right gauge, too. For example, a 0-30 psi gauge will work well with a 100-ft hose for small heads. The same gauge can be used with a 50-ft hose for larger heads (steeper terrain).

Additional hardware is added to keep water in the hose during shifts between readings and to aid in draining the hose at the lower end. I used a plastic Y-fitting at the lower end. It's the kind that threads onto an outside faucet so two hoses can be attached. It has two ball valves that rotate through 90° to open or close. One branch doubles as a drain or fill valve. The other isolates the gauge from the hose pressure. Additional fittings are needed to

(Right) Different wheels and turbines fit various combinations of head and flow.

(Below) Hardware for the hose-and-gauge survey method.



mate the gauge with the plastic Y-fitting. This will depend on the type and size of thread on the gauge you find. If you take all the parts to a hardware store, you can usually figure out what you need or get some help.

Got all the parts? Assemble the hardware using pipe thread tape to avoid leaks. Test it before you haul it out into the brush. With the gauge assembly sitting on the ground, elevate the other end of the hose (up a slope or on the roof) to a known value and fill it full of water. Read and calculate. Everything check? Great. Is the gauge reading off? Adjust it (if it has this ability) or note the corrected value. Check it against other test readings. Use these to adjust your survey readings to the corrected ones before you make any calculations at the end.

Start the survey

This process is easily done with two people: the gauge reader and the holder. Survey from the bottom up or the top down. If you know where the hydroturbine will be sited, start there and work up. The last site I surveyed had easy access to the uppermost point, so I started the process there. Reverse it for a bottom-up approach.

The gauge reader starts downward first. The other person's job is to hold on to the other end of the hose. When the reader has stretched out the hose, the holder yells stop. At the upper end, the holder opens the valve and refills the hose full from a quart water bottle. Then, the reader opens the lower valve (between hose and gauge) and records the psi reading. This may be done at waist height or at ground level. The reader and holder need only be consistent with each other throughout the survey

Got the reading? Both people close their valves and hang on to their end of the hose. If the holder is close enough to see the reader, he or she may head downhill until reaching the exact same position. At the same time, the reader may head down until the hose is again taut. If the holder can't see the reader's position and accurately find it, the reader should wait until the holder arrives. This will place a loop in the hose, which will try to catch on every little thing, but—be patient. (Next time, I'll leave orange peelings at these points to speed up the process.) Repeat this procedure all the way down the hill.

A word about downhill readings. Remember, you're not out to record the length of the streambed. You're trying to find out the available pressure and head and, if possible, the length of tubing your installation will require. So, even if your stream meanders, you shouldn't, unless it's the best way to avoid brush. Survey by moving directly downhill. If your stream is a wild one in the winter, the inlet pipe should leave the streambed in the most direct way. Of course, if there is a more direct way to reach the site of the hydro-electric unit, go that way. The shortest distance between two points is a straight line. You may not need to follow the streambed at all.

The last reading you take in the survey is where you want to stop, at the hydroelectric site or at your property line. Approximate the length of the last section, even if there's not much of a reading, and make a note of the adjusted length of the hose. Take the last reading at ground level, right where the hydro unit will sit.

All done? Sit down at a table with your paperwork while you're still fresh from the experience.

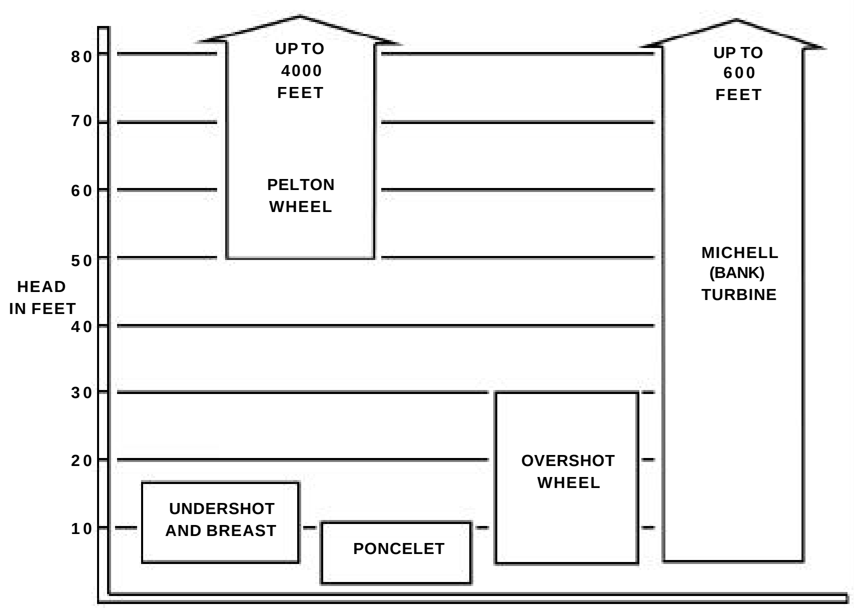
1. Add up all the pressure readings. If the gauge was found to read a little off, adjust the written values accordingly. This is the total pressure in your system. Record it; it will be useful when you select the schedule (psi rating) of pipe.

2. Multiply the pressure reading by 2.3 ft/psi. The answer represents the number of feet of head between intake and outlet.

3. Add up the number of readings you made. Multiply this value by the length of your hose. The product is the approximate total length of pipe your system will need (if you traced the pipe's route).

Find the rate of flow

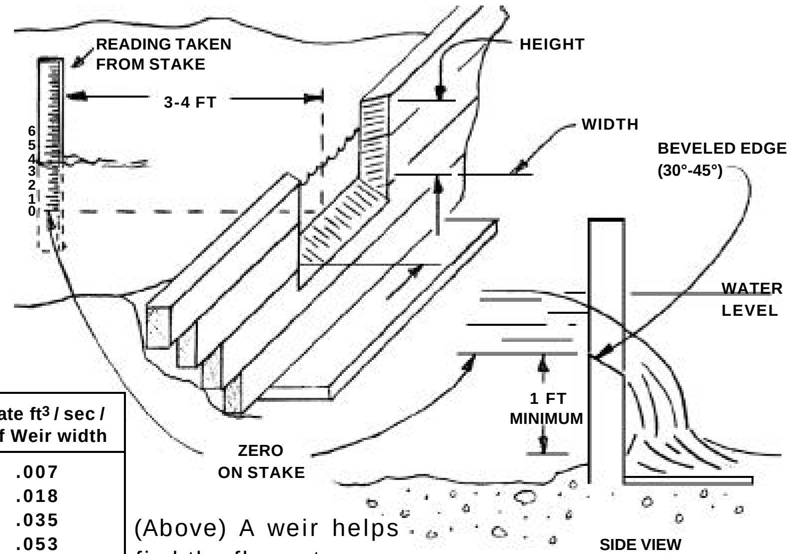
The second vital portion of the hydro survey is to find the actual flow of water in gpm or cfm. Gpm is gallons per minute and cfm is cubic feet per minute. The first is used with flows of 5-50 gallons per minute. Beyond this rate, cfm is used because, at about 7.5 gallons per cubic foot of



water, it can handle the bigger numbers.

Which one fits your site? Answer this question: How big a pipe would you need to channel all or most of the stream's water through it for a few seconds? A 2-inch diameter pipe? A 6-inch? A 12-inch? If your answer is 6 inches or higher, you must measure flow another way, i.e., a weir.

A. Using a bucket. To measure a relatively small flow, you will need three things: a pipe, a container, and a time piece. The pipe can be a short section of large diameter plastic tubing. Find a spot where you can lay the pipe and make a small dam around it and the immediate area. You're successful when most of the water in the streambed is forced to flow temporarily through the plastic pipe and directed into a 2-gallon or 5-gallon bucket.



(Above) A weir helps find the flow rate.

Depth (inches)	Flow rate ft^3 / sec / inch of Weir width
1	.007
2	.018
3	.035
4	.053
5	.075
6	.098
7	.123
8	.152
9	.180
10	.212
11	.243
12	.278
13	.313
14	.352
15	.388
16	.428
17	.468
18	.510

(Left) A weir table converts readings into a factor for flow rate calculations.

Generally, the longer it takes to fill the bucket, the more accurate the measurement. The time piece should read in seconds. The idea is to note the time you first put the bucket under the pipe's flow of water and the time the bucket reaches full. The *difference* between the two times is the elapsed time. Repeat this process until you get a fairly consistent value for the elapsed time.

Use a container of known capacity to fill and discover (or verify) the gallonage of the water your setup will capture.

For example, suppose that our diversion pipe fills a 5-gallon bucket in 10 seconds. What's the flow rate in gpm? One gallon per minute is the same as 1 gallon per 60 seconds. At a rate of 5 gallons in 10 seconds, we'd fill a 30-gallon bucket in 60 seconds, or 1 minute. Thus, the calculated rate of flow is 30 gpm.

B. Using a Weir

Larger flows of water need a different technique. If it only takes 2-3 seconds to fill a 5-gallon bucket, you've got lots of water but probably a poor measurement. In this instance, you might consider using a weir.

A weir is a simple dam with a particular shape to its top. It goes across a streambed and is sealed so that all the stream's water flows through the beveled aperture. It's basically a low-level dam which directs and smooths the flow of water enough to take a measurement of its height above the bottom of the weir.

How does it measure flow rate? The depth of the water in front of the weir is measured with a ruler and looked up in a table. This represents a flow rate/inch of weir. This is multiplied by the width of the weir and a conversion factor.

An example. The water just reaches the 6-inch mark on the ruler upstream of the weir. In the table, 6 inches of depth is equal to 0.098 ft^3/sec./inch. Multiply this figure by the width of the weir (i.e., 24 inches). The flow rate is 2.352 ft^3/sec.

Since a cubic foot (ft^3) of water equals approximately 7.5 gallons and 1 minute equals 60 seconds, we can find the flow in gpm by multiplying 2.352 ft^3/sec by 7.5 gal/ft^3 by 60 sec/minute. The product is 1,058.4 gpm.

Once installed, the weir will permit multiple readings through a season, establishing the highest, average, or lowest readings. This technique will yield a good profile of water sources which are seasonal or only runoff in nature. A long-lasting weir has to be well constructed and the owner/builder will want to read up on the design and construction issues it embodies to survive heavy flow and debris, i.e., rocks and tree parts.

Calculate power

Once you have numbers for the the flow, you're ready to plug them into the formula that will tell you the maximum amount of power the water's energy will generate in the form of electricity.

There are a variety of water-harnessing turbines and wheels that cover the span from small flows and big head to big flows and small head. Owner/builders will have some choices of turbine or wheel types in the middle range. Otherwise, the site will dictate the hardware specifications.

Power transmission

There are a few things to know about the hydro-electric system. Again, the inlet is the point where the water is diverted into a pipe or channel and the outlet is the hydroturbine itself.

It is ideal when you can locate a hydro-electric turbine very close to the battery bank it will charge or the electric loads it will power. At the same time, it should be positioned so that the water discharged from the turbine will go back into the natural streambed, or an adjacent streambed, or storage that will make other use of the water. Site the turbine above the high-water mark at the outlet point. In a high flow, it can be inundated by water and become inoperative, or risk being swept away by the flow or debris.

The reality of your layout may require that the hydro-turbine be located downstream of your building site. As the distance between unit and usage increases, so will the expense in getting the generated electricity from the turbine to the loads it feeds.

Low-voltage systems will suffer most, since large (expensive) wire will be needed to avoid line losses. At some point, the extra power generated by the hydroturbine must be balanced against the cost of the pipe and the wire needed to reach it.

There are several design strategies for handling a growing distance between the hydroturbine site and point of use.

1. Use a higher system voltage. A 24-volt system will transfer power with only ¼ the line losses of a 12-volt system for the same length and size of wire. Thus, electricity from a hydroturbine in a 24-volt system can use ¼ the wire size to transfer the same power at the same loss rate experienced in a 12-volt system. Or travel four times as far with the same wire at the same loss.

2. Invert the low-voltage dc power into high-voltage ac power, i.e., 110V, 60-cycle ac. This works if the turbine is located near (or in) a building that contains the battery bank and inverter.

3. Use two dc-dc converters to transfer power. A dc/dc converter is a high-frequency electronic circuit that will step up the voltage of the hydroturbine's output to a few hundreds or thousand volts for transmission along a relatively small wire At the other end, a similar dc/dc converter steps the voltage back down before it is routed to the battery.

In any case, the rule is "low voltage, big wire; high voltage, little wire" when it comes to distances.

Hazards

A few things to think about:

1. **Loose pipe.** What happens when plastic pipe used in your hydro system is laid over hard ground or decomposing granite on steep slopes? It slides. Pipe should be tied off periodically to trees or fence stakes. A 20-foot section of 2-inch pipe is fairly light. Full of water, it will be heavy. Use 3/16-inch polyrope to tie the pipe loosely to a likely anchor.

2. **Freezing weather.** If your stream freezes periodically or your area suffers hard freezes, your hydrosystem could be at risk. Free-running water in a pipeline doesn't want to freeze. If the system is stopped and full of water, a hard freeze could damage it. Either let it run free or drain the system.

3. **Legal and ethical use**. Let's talk the law. Do you have legal right to use some or all of the water that crosses your land? If you don't know, find out. This is crucial to avoid later conflicts or legal action.

There are different types of rights regarding water use. What type exists in your area? Most areas forbid in-line ponds for seasonal or year-round use since downstream sites are at risk in case of dam failure or spurious flow. Fortunately, most small-scale hydro-electric systems can generate sufficient power with only a fraction of the water available. This also circumvents any concern about drying out a section of streambed.

4. **Being hydro savvy**. You may be your own best advocate for using hydro-generated power to people who could pull the plug on your dream. Don't expect them to know anything, or anything useful. The ability to gently educate others and avoid aggravating anyone unnecessarily will go a long way toward project approval.

For example, point out the fact that hydro-electric turbines do not use up the water, they only make use of the water's energy. Even if you have no legal right to the water itself, you may simply generate power from it and return it to the original streambed.

5. **Using runoff.** Don't scoff at the idea of using runoff if that's all you have. A friend with a PV system was happy to discover that he could use a hydro system to do two things:

a. Supplement his energy system with hydro-generated electricity from runoff of winter rains. He does not have a seasonal flow. It lasts for the duration of the storm and a bit after.

b. Route the runoff past fertile ground it had been eroding through first a channel and then down a pipe into the hydro system. This proved the least expensive way to treat the erosion problem. The system cost slowly pays itself off with the winter electricity it provides and the standby generator it idles.

(Some photos and drawings are taken from the waterpower chapter in *At Home with Alternative Energy*, Michael Hackleman, Peace Press, 1980, 148 pages. Available in libraries, or from Michael Hackleman, P.O. Box 327, Willits, CA 95490. E-mail: mhackleman@saber.net) Δ