






Installing a hydro system

A low-buck, low-tech approach to tapping a water source for power

[This is the third in a series of articles on hydropower which details the processes and hardware involved. In *Do-it-Yourself Hydro Survey* (*BHM*, Jan/Feb 2001), a site survey established the potential to generate power from the seasonal flow of water in two streams. In *Restoring A Hydro Unit* (*BHM*, Mar/Apr 2001), the alternator of a Burkhardt turbine was rebuilt and a simple, practical control circuit was fabricated for it. This article reflects the beginning of the actual installation of this hydroturbine (a high-head, low-flow, Pelton-type unit) at Motherland outside Willits, California.]

By Michael Hackleman

A site survey and the restoration of a used Burkhardt turbine brought Donna D'Terra closer to the installation of a hydro-electric system at MotherLand. Her home in the canyon receives little winter light for the solar panels mounted on its roof. Soon, the two seasonal streams that would power the system would be flowing.

The first job was to locate the intake. The intake of a hydro system is the point where the water diverted from a stream is channeled into a pipe to flow and build pressure so the hydro unit (located much lower) will work.

At Motherland, a road to the upper portion of the property cut across two seasonal streams above their point of convergence lower down. The outflow of the two culverts used to channel the water under the road seemed a natural point to divert water while avoiding some of the hazards and challenges of installing an in-stream intake.

Using the hose-and-gauge method, I found the 300+ foot distance between the intake and the site of the hydro unit to have a head (vertical distance between these points) of approximately 100 feet. In the middle of the previous winter, I used the tube-and-bucket method of gauging the rate of flow in the stream at the base of the hill to be 24 gpm (gallons per minute). Observation suggested that one culvert had twice the outflow of the other, so I deduced a 16-gpm flow in the north fork and an 8 gpm in the south fork of these streams.

The scope of the installation was simple to state. Divert the water from two culverts into a sediment-catching barrel, filter it, and have it gravity flow to the hydro unit where it makes electricity that is routed to and interconnected with the existing solar array and battery pack.

For a number of reasons, I opted to do this installation as a learning experience. As such, I reached an agreement with Donna D'Terra on how this would work and the project began.

I had goals. Keep it simple. Obtain off-the-shelf parts from hardware stores or materials found around the shop or house. Use simple tools, hand or electric. Keep it low-tech and low-buck.

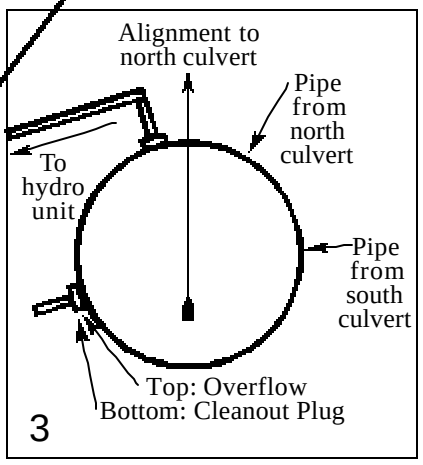
I will describe the installation as it actually unfolded. For example, while I had *ideas* on how to divert water from the culverts, I wanted to pare these down to one, fabricate the hardware, and install and test it *before* I wrote about it. Since I have limited experience with hydro-electric systems, I opted to start with stuff I knew I could do, giving ideas on how to do the more complex parts time to simmer and gel.

Accordingly, I fabricated and installed the sediment barrel, intake filter, and pipe track. I also attached and wired the homemade control box to the hydroturbine, bore-sighted its nozzle/jet assembly, established where the hydro unit would be positioned, sized and installed the electrical wiring that would connect it with the existing solar-electric system, and assembled some of the system's plumbing—all of which is covered in this article. Subsequently, I will cover the installation of the hydro unit, monitoring system, and the water diversion assemblies at the culverts.

Sediment barrel

Early on, I decided to isolate the hydro system's intake (where the water enters the pipe to the hydro unit) from *direct* connection to the culverts (the source of the water) by using a sediment barrel. I chose a 55-gallon plastic barrel for this job. I needed to position it slightly downhill of the outlets of both culverts. I figured to divert water from the two culverts via 2-inch pipes. I wanted to direct the outflow of these pipes at a *shallow* angle onto a screen covering the barrel's top. This should ensure that leaves, rocks, and other material in this swift flow of water would fly across and off the barrel's screen while the water would fall through it and fill the barrel. In turn, this water would be sucked through the intake filter (positioned halfway up the barrel) and into the pipe track feeding the hydro unit in the valley below. The barrel would need both a clean-out plug and overflow port.

I positioned the barrel before I did any work on it. When the barrel was filled with water, it would weigh 400 pounds. So, I was looking for a site that was *solid* and slightly lower in elevation than both culverts. At this



1. The sediment barrel is just visible downhill of the north culvert and roadway.

2. The contour of the barrel is impressed in the concrete base to level and help retain it.

3. An onsite drawing of the relative angles of pipes and fittings prevents mistakes back in the shop.

site, the best option appeared to be a large cluster of big rocks alongside one creek bed. A line of small trees led down to it, supplying handholds and giving good access to the barrel even in poor weather conditions. I took the barrel down there, propped it in place, and assured myself the site met the criteria *and* gave good access to the pipe track.

It took 1½ bags of concrete to make a secure foundation for the barrel. I had some help from Jem Klein, a young man who lives nearby and helps Donna with projects. We mixed the concrete up in a wheelbarrow on the road, Jem ferried it down in a bucket, and I set and shaped the foundation.

Concrete is the universal adapter, binder, and stabilizer. While the wet mixture shaped itself to the terrain underneath it, I set the barrel into the concrete mush, rotating it until its own mold line was aimed at the northern culvert up the hill. Then, I pressed down hard on the barrel, impressing its unique shape (of bottom) into the concrete. I also sculpted the mix surrounding the barrel to shed water and stabilize the overall structure.

I left the barrel in place while the concrete set and hardened over the next week. Since the barrel's position was literally set in concrete, Jem and I next installed the pipe track.

A week later, I drew a large circle on a piece of paper, climbed down to the barrel, and set it on top. Since I intended to modify the barrel in the warmth of my shop, I needed to know *exactly* where everything would go (Fig. 4). I drew a reference line on the paper to the mold line on the barrel which had been aligned with the culvert when set in the concrete.

I first noted the best place to locate the drain plug. Fine sediment that makes it through the screen settles to the bottom of the barrel. To clean the accumulated matter out periodically *without* upending the barrel, I wanted a 2-inch plug on the side, near the bottom, and facing the creek. When this plug was unscrewed, the 25-50 gallons of water released from the barrel should splash away harmlessly and not erode soil or foundation. I noted, on both the paper circle *and* the barrel, the relative angle to this cleanout plug.

Next, I positioned the overflow port. Since I wanted any water directed out the overflow (with pipe and fittings) to land on the same rocky streambed, I aligned it with the cleanout plug below.

The hole for the intake of the hydro system was tricky. I knew I wanted it about midway up the barrel's side. Somehow, though, I wanted to be able to remove the intake pipe (stiff) from the barrel (heavy) *without* having to drain the barrel. This led me to position the intake's hole a quarter of the

way around the barrel and at a 90° to the pipe track. I noted the relative position of the intake on the drawing and barrel.

Finally, I noted the approximate points where the two feed pipes from the culverts would intersect the barrel. While they didn't require holes, I would need to figure out some way to secure these pipe ends to the barrel's top. Drawing and notes complete, I hauled the barrel up to the roadside and brought it home.

I used a saber saw to cut out the 2-inch holes for the cleanout plug, intake, and overflow fittings. It was a challenge to make watertight fittings. Threaded PVC couplers and fittings exist but the inside and outside pieces wouldn't pull together snugly against the barrel wall. Alas, their threads are tapered. As well, the cleanout plug and overflow port were located in areas where the barrel had a compound curve.

Steve Henderson at nearby Ukiah Valley Lumber clued me into the 2-inch nuts for EMT (electrical metallic tubing). They are *not* tapered and, thus, will spin all the way onto the threads of the PVC adapters (or any threaded pipe). Combined with a generous coating of silicone sealant, all three fittings (cleanout, intake, and overflow) were secured tightly through the barrel walls.

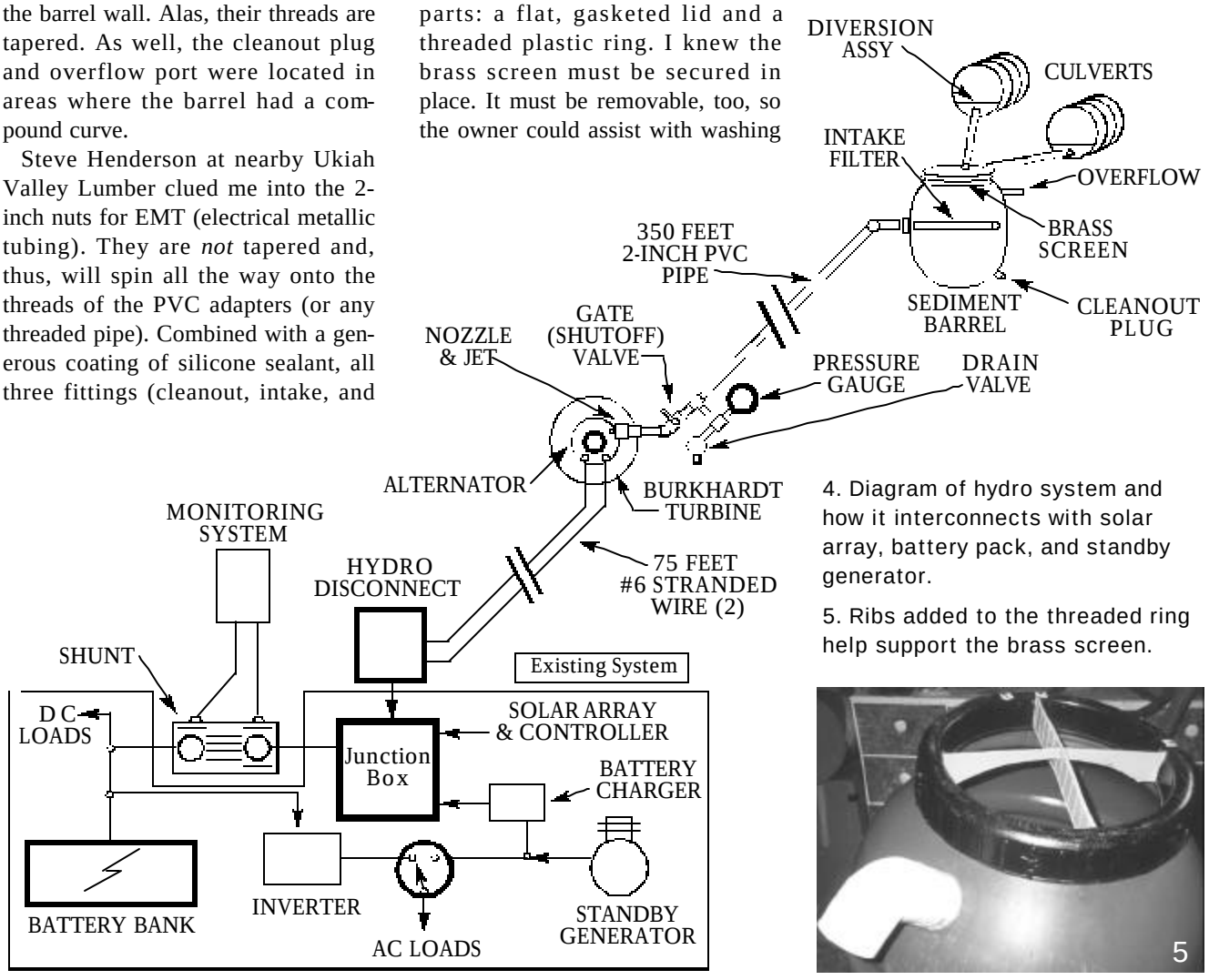
Actually, I wasn't worried if the fittings leaked somewhat. The barrel is *not* a storage tank. In operation, the hydro unit will want 22-24 gallons of water per *minute*. So, even a leak of one gallon *each* minute from the barrel would impact this flow rate by a scant 5%.

I needed a screen at the top of the barrel. Plastic screen is weak and vulnerable to sunlight. Aluminum and metal screen are subject to corrosion. Local hydro expert, John Takes, recommended brass. I finally found 1/16-inch brass screen on a 24-inch wide roll and purchased 3 linear feet of it.

I examined the top of the barrel and the lid. The lid consisted of two parts: a flat, gasketed lid and a threaded plastic ring. I knew the brass screen must be secured in place. It must be removable, too, so the owner could assist with washing all the sediment out whenever the cleanout plug was pulled. I could see no future for the lid and discarded it.

I retained the 14-inch diameter ring and laid it over the brass screen on my workbench to figure out how to secure the two together. The ring was a bit more than 2 inches deep. I figured to fold the screen over the outside of the ring and clamp it. That added 1½ inches on each side of the ring for a screen diameter of roughly 17 inches.

I found a round laundry basket in the house with this same diameter, placed it over the screen, and used a marker pen to draw out the circle's cut line. I tried to cut the brass screen



4. Diagram of hydro system and how it interconnects with solar array, battery pack, and standby generator.

5. Ribs added to the threaded ring help support the brass screen.

6. Plastic ties hold the brass screen to the lid.

7. A bicycle inner tube covers the sharp edges of the brass screen.

with tin snips but they gagged on the soft material. A utility knife didn't help much either. I had wanted to avoid ruining any scissors but tried the worst pair I owned. Darn it, the brass screen cut easily.

Next, I snipped 2-inch long cuts in the brass screen (toward the circle's center) every few 2-3 inches around the circumference. This produced tabs which, when bent, would overlap one another when forced through a 90 angle. I bent each one of the resultant tabs along the circle marked on the screen. Now the screen curved beautifully around the corners.

Next, I considered how to compress a wire or band around the ring and over the brass tabs that would also prevent the screen from slipping off. The plastic ring had an intricate pattern of outside ribs on it, with six of them a little larger than the others. Instead of reaching for a file to cut a ¼-inch slot through each one of the plastic ridges (so the band would find a grip), I reached for my soldering gun.

Soldering guns have replaceable tips. I positioned a spare tip on the anvil of my vise, hammered the tip flat, and used a file to make a fine edge on each side. I inserted this knife-edged piece into my soldering gun, pulled the trigger, and applied the heated tip to a portion of the plastic ring. The hot tip flattened the slot in the ridge like a warm knife through cold butter. The smell generated from this test reminded me to take this job outside my shop where I notched all six ridges in a few minutes.

I didn't like the way the brass screen sagged down in the center of the ring. Leaves and other debris could get trapped in this slight hollow, diverting the flow or eventually tearing the screen. Again, I used the heated tip of the soldering gun to fashion four, thin ribs out of a piece of scrap plastic sheet. I joined the ribs together with silicon sealant to span the center of the ring and converge at a point higher than the edges, giving a slight convex (rather than concave) shape to the screen.

[Note: When it comes to working plastic, I prefer a soldering gun over a saber (jig) saw. They are less expensive than a saw, use less electricity, are silent, are easier to use, and won't chip or shatter plastic. They *will* produce vapors you don't want to breathe, so do this work outside and stay upwind of the work. A 50-watt soldering iron is cheaper than a gun and will work, too, although more slowly. Both are available from electronic supply houses or places like Radio Shack.]

How would I hold the brass screen in place while I positioned and tensioned the band that would secure it? Rubber bands popped into my head, won out, and proved perfect. I made a long rubber band by joining individual bands together. (If you don't know how to do this, ask a kid.) It took me four #64 bands to span the circumference of the barrel ring and I joined its ends together with a paperclip. Positioned just so that it held the tips of the brass tabs with the screen in place, the rubber band is easy to progressively lift over each tab of screen that is brought under it.

I threaded some 12-inch plastic ties together to make a larger thin band to affix the screen to the ring. I tensioned it by degrees, pausing to maintain tension in the brass screen across the face by pulling on different tabs.

I punctured and sliced my fingers on the exposed edges of brass screen several times as I was fitting the band. As the screened ring would need to be removed (and replaced) several times a season, I *had* to fix this. I wished for a big, wide, thick rubber band. That led me to think of a used bicycle inner tube. The owner of Dave's Bicycle Shop in Ukiah gave me a spent 26-inch tube and I tried several ways to attach it to the screened lid. Since the tube was nearly twice the diameter of the barrel's lid, I knew I would have to wrap it around *twice* to fit. I was worried that, if the band slipped, it would crumple the screen as it came off.

After a few tries, the process that *worked* to affix this tube was to orient the tube with the air valve (its innards unscrewed to expel all air) close to me, position the opposite side of the band on the far side of the lid (while it was attached to the barrel), and stretch and slip the band around the circumference in both directions until they met on the side near me. While I used one hand to clamp this junction, I placed all the slack tube up on the screen and rotated the barrel 180°. With my belt buckle now holding the junction, I used the other hand to stretch the tube (and the air valve)

across the barrel, pulling the tube around the lid on each side. I nudged the rubber tube over any exposed edges of screen until everything was smooth.

Intake filter

While the concrete pad for the barrel was still hardening, I fabricated the intake filter.

Pelton type hydro units are susceptible to pitting of the plastic or brass buckets by very fine sediment in the water. A jet of water and sediment at 50 psi (or greater) has a sandblasting effect on the Pelton wheel, spoiling its efficiency and, eventually, destroying it. A filter at the intake (located inside the sediment barrel) afford the last opportunity to reduce the size and amount of sediment that reached the hydro unit. [Never plumb a filter or any other flow-restrictive device near the lower end of the pipe track where it attaches to the hydro unit itself.] I'm certain off-the-shelf filters exist that will work in this application but I decided to make one from scratch.

A popular filter for the intake of hydro units is a larger pipe drilled with many tiny holes and set into a stream. This works for high-flow systems where volume rather than pressure drives the hydro unit. In Motherland's system, the brass screen on the sediment barrel reduced the foreign matter to $^1/_{16}{}^{th}$ of inch in size. I wanted the intake filter, then, to strip away the really small stuff in the water that made it through the brass screen.

The first job was to figure out where the filter would go. Since I wanted it to be easy to remove, inspect, and replace, I looked to put it inside the barrel. I selected a PVC adapter in the sediment barrel at the hydro's intake which had threads on the outside—to secure the fitting to the barrel *and* make the connection to the pipe track—and a coupler for a 2-inch pipe on the inside. The inside of the barrel was 22 inches in diameter. I cut a 19-inch long piece of 2" PVC tubing (the same used in the pipe track) to serve as the *core* of the filter and fitted a cap at one end. The other end would SLIP into the coupler fitting for the intake (without glue), positioning the filter halfway up from the bottom and suspending (and supporting) it horizontally in the water across the width of the barrel. To remove, it need only be twisted and pulled away from the coupler and lifted out of the barrel.

With a filter, the finer the mesh, the harder it is for the water to pass through it. A way around this resistance in any filter is to increase the *ratio* of the *filter* area (combined area of drilled holes) to the *intake* area (2-inch diameter pipe) by a factor of two, three, or more.

My plan was to drill many holes into the filter's PVC core and cover it with a fine cloth or fabric. But— what *size* of hole and how *many*? First, I had to find the cross-sectional area of the 2-inch intake. Second, I had to establish a reasonable filter-to-intake ratio. Finally, I needed to establish the size and total area of the holes I drilled. I had a shiny new ¾-inch wood bit I wanted to use, so I did my first calculations for this size of hole in the filter core (Sidebar A). The math said I needed to drill 24 holes.

I reserved 2 inches at each end of the 19-inch filter core for fittings and ties to hold the screen and fabric, leaving roughly 15 inches of the pipe in which to drill holes. If I spaced 4 lines of holes equally about the pipe's circumference, I could easily get 6 holes in each line spaced 2 inches apart.

I was ready to draw a hole-drilling template for the pipe. This is a neat little trick to position holes accurately around the perimeter of a pipe for drilling. Generally, the template is used as a guide for drilling pilot holes (a small size of hole to keep a larger drill bit from wandering) which

Sidebar A: Math of filter-to-intake ratio and size and number of holes.

1. Intake (cross-sectional) area.
   Pipe I.D. (inside diameter) = 2 inches, radius = 1 inch
   Area = $p \times r^2 = 3.1428 \times (2.375/2)^2 = 3.73$ in^2
2. Drill size = ¾-inch = 0.75 inches, radius = 0.375 inches
   Area = $p \times r^2 = 3.1428 \times (0.375)^2 = 3.1428 \times 0.141 = 0.44$ in^2
3. Filter-to-Intake ratio = 2.5 to 1 (arbitrarily selected)
4. Total filter area = filter-to-intake ratio x intake area
   $= 2.5 \times 3.73$ in$^2 = 9.325$ in^2
5. Number of ¾-inch holes = filter area divided by hole area
   Holes = 9.325 in$^2 \div 0.44$ in$^2 = 21$
   Number of ¾-inch holes actually drilled = 24
6. Additional ½-inch holes drilled = 20
7. Drill size = ½-inch, radius = 0.25
   Area = $p \times r^2 = 3.1428 \times (0.25)^2 = 3.1428 \times 0.0625 = 0.20$ in^2
8. Total area of ½-inch holes drilled = 20 x 0.20 in$^2 = 4$ in^2
9. New filter area = 9.325 in^2 + 4 in^2 = 13.325 in^2
10. New filter-to-intake ratio = 13.325 in$^2 \div 3.73$ in$^2 = 3.5$ to 1

8. Inside view of the 2-inch filter core after drilling.

Sidebar B: Making a hole-drilling template for 2-inch PVC pipe

1. Find the outside diameter (O.D.) of the 2-inch pipe. Using a ruler, I measured the O.D. at 2.375 inches.
2. Find the circumference (C) of the pipe.

C pipe = p x O.D. = 3.1428 x 2.375 inches = 7.5 inches

3. On the grid paper, near the top, mark two points 7.5 inches apart horizontally.
4. Wrap the paper tightly around the pipe. Note that the overlapped paper aligns one of the marked points directly over the other.
5. Select points equidistantly (½, ⅓, or ¼ of the way.) *between* the two initial points to space, respectively, two, three, or four (or more) lines of holes around the pipe's circumference throughout its length. Remember: one line of holes is for reference only. When the paper is wrapped around the pipe, this reference line sits atop another line of holes.
6. Establish the spacing between the holes. Even with 2 inches between the holes in a line, I didn't use all of the 15 inches of pipe length available to me. As well, to maintain structural integrity of the plastic pipe, I opted to offset the holes in adjacent columns.
7. Make additional copies of the template and overlap them for any length of pipe.

9. A hole-drilling template is wrapped around the 2-inch filter core.

10. The template is removed after the pilot holes have been drilled.

11. Plastic ties secure brass screen around the core before the fabric is attached.

12. A fine mesh of nylon fabric is wrapped around the screen on the filter core.

13. The filter is inserted into the intake fittings in the sediment barrel. Note the overflow and cleanout fittings.

would then be enlarged with the ¾-inch bit.

I made my template on the computer and printed it out. However, the template is easily drawn with pencil and paper (Sidebar B). I recommend using blue-lined grid (graph) paper, 4 or 8 squares per inch, for the template.

I taped the template to the filter core, overlapping extra copies of it to handle its length. I drilled the pilot holes, removed the paper template, and chucked the ¾-inch bit into the drill. Incidentally, I don't recommend using standard (metal) drill bits of ½-inch or larger for PVC pipe. The plastic material is soft enough to grab the bit but brittle enough to chip and crack if you resist its tendency to pull the bit rapidly through the pipe wall. Using wood bits proved less stressful. After drilling all the holes, I used a long, large, quarter-round file to smooth the rough edges of the holes, inside and out.

As I looked over the hole-studded core, I felt apprehensive. Had I drilled too *few* holes? I opted to add four *more* lines of holes between the existing ones (Sidebar A). I selected a smaller, ½-inch bit for this job as I was afraid extra use of the ¾-inch bit might shatter the PVC pipe. The extra

holes boosted the filter-to-intake ratio to 4:1 and I felt better.

I visited a local fabric shop to search for a suitable material to use as a filter cloth. I wanted something that wouldn't rot, clog, or swell when submerged in water. I got half a yard ($6) of a thin nylon fabric with a weave finer than that of the brass screen. [Later, it occurred to me that used nylon stockings would probably work if one avoided the sections with runs.]

I elected to *first* wrap leftover brass screen around the holes in the filter core and *then* apply the fabric. Why? A Pelton-type hydro system, once set in motion, creates strong suction on the intake filter. I didn't want the fabric to dimple into the holes in the PVC core as a result and be cut by their rough edges. The brass screen prevented this, supporting the filter's nylon fabric across these openings.

I wrapped brass screen around the filter core (with a slight overlap) and used plastic ties to secure the ends and middle. I cut the nylon fabric a little wider than the screen, wrapped it twice around the filter core, and also secured it with three ties. These may be cut away if the fabric becomes clogged and needs replacement.

Pipe track

After the sedimentation barrel was positioned and secured, it was time to lay the pipe. Whether one lays the pipe track working up from the bottom or down from the top depends largely on access to these points. Walking uphill with pipe is lots of work, while walking downhill with pipe is only sometimes challenging. Either way, slippery pipe on steep slopes is a rollercoaster waiting to launch the moment we were careless about handling or securing it.

Donna purchased 300 feet of 2-inch Schedule 40 PVC pipe, which is designed for higher pressure (280 psi) than the more standard (*and* less expensive) Schedule 80 pipe. This system would only experience 50-60 psi but it was the thicker wall I wanted to handle the hardship of rough terrain and above-ground use. A truck containing 15 lengths of 20-foot pipe was driven to the upper end and unloaded.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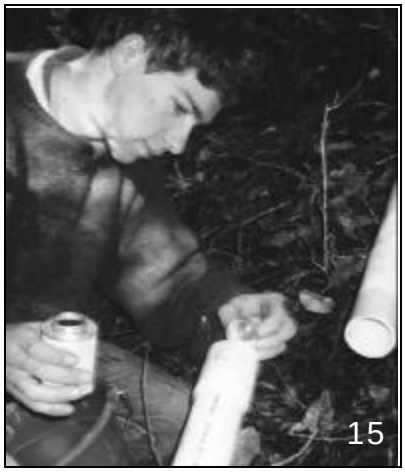
14. The pipe track stretches uphill and across a streambed.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15. Jem Klein adds PVC glue before joining pipe sections.

The initial 120 feet of pipe exiting the sediment barrel would traverse a steep, nearly impassable slope before it crossed the stream onto more solid ground. Jem and I schemed on the best way to get the pipe started. Since 20-foot sections of this 2-inch pipe are fairly light (13 lbs), we elected to join three 20-foot sections together on the roadbed. After the glue was set, we "noodled" the 60-foot segment down into position, which worked because the pipe is so flexible. We repeated this process again initially and it helped us bridge the most inhospitable portions of the track with only a few joints to glue and tie off. Since the pipe track paralleled the upper road for awhile, we temporarily joined 20-ft segments together and lowered them to the pipe track at a convenient point, stockpiling them until we needed them.

If you haven't joined plastic pipe before, you'll be happy to know it's pretty straightforward to do. If possible, purchase pipe that has a bell at one end, which means the pipe flares out to become the coupler for the next section. This is less expensive than buying uniform pipe that can only be joined by a separate (expensive) coupler.

PVC plastic pipe is joined with a glue that actually softens the plastic at the joint so that the sections weld together. To help this bond, the end of each section to be joined is first cleaned with a damp cloth, dried with a second one, and coated with a purple PVC primer. This reduces the emissions (vapor) from the glue when it is added. (Read and heed the instructions on the can. This is nasty stuff.) The cap of the primer and glue cans has a built-in applicator that is ball-shaped. By gripping the cap tightly with the fingers, each can be evenly applied in a rotary motion to both sections at the joint. The protocol is to swab each on the *inside* of the bell coupler first. This way, it won't be contaminated if the pipe touches the ground while you're swabbing the *outside* of the other section before joining the two ends.

While the glue is still wet, the pipe end is inserted into the bell (until it bottoms out) *and* twisted as much as

¼ turn. Hold the two ends together for 10-15 seconds (double this for a steep slope) for the join to set or it may pull apart. Thereafter, the pipe should not be moved, bent, or otherwise disturbed for at least five minutes or the join may leak. During this time, Jem and I would bring up the next pipe section, position it, clean the ends, and prepare the next join.

Soil, small stones, and organic debris will find its way into the pipe during this process. It is unavoidable. Of course, this debris must be flushed out of the pipe track *before* the pipe is connected to the hydro unit. Once the streams start to flow, I figure to run through a few fill-and-flush cycles.

The pipe track should be *loosely* tied off periodically (every 10-20 feet of its length). The trunk or large branches of trees will work as anchors. If none are available, use stakes. The pipe track *must* be secured. A 20-foot section of 2-inch pipe will weigh 46 pounds when filled with water (Sidebar C). This 300-foot long track of pipe, then, will weigh 690 pounds in service, so I did a good job.

16. The pipe track is secured every 10-15 feet with nylon rope. Don't bind it tight to the anchor point.

[I'll pass on a story I've heard from several sources. The proud owner of a newly-installed hydro system discovered that, after a rainy night, it had stopped generating power. When he went to investigate, he found all 1,200 feet of track pipe at the base of the hill in one big, very twisted and broken pile. *It had not been secured*.]

I used 3/16-inch nylon line to secure the pipe. It won't degrade with exposure to weather as ropes will. I used a pocket lighter to heat and fuse the two ends produced when the nylon line was cut to prevent unraveling. In the steeper sections, I wound duct tape over the rope wrapped around the pipe to ensure it will not slip.

At one point, the track pipe crossed a streambed. I selected a crossing where there were mature trees on each side that already spanned this gap. Again, I used nylon rope to help suspend the pipe above the highest possible flow of water and from branches or trunks that would move very little in the wind. Since trees grow, sway, and even fall down, the pipe track should be walked after each season to loosen or tighten the nylon line at anchor points and detect any leaks.

Where possible, the pipe should lay flat on the ground where it will be sheltered from low ambient (air) temperatures. As others have done, Donna plans to lightly cover the pipe along many sections of the track with soil and leaves to further increase this protection. Water flowing in a pipe is less likely to freeze than water which is stationary. Still, the hydro unit can be shut down and the pipe track emptied of water for brief periods of subfreezing temperatures. Folks in colder climes may need to bury the track pipe and add insulation to the pipe where the terrain prevents burial.

It is important to ensure a slight downward angle *throughout* the length of the pipe track. Any high spots in the pipe track can and will trap air, adversely affecting system performance. If this is unavoidable, add a water valve at each high point to bleed off accumulated air, as needed.

Sidebar C: Weight of water in a 2-inch PVC pipe

1. Area of 2-inch pipe per foot = 3.73 in^2 (from Sidebar A)
2. Convert square inches to square feet
   - 1 ft^2 = 144 in^2 (conversion factor)
   - = 3.73 ÷ 144 in^2 per square foot
   - Area of 2-inch pipe = 0.026 ft^2.
   - Volume of 1 foot (length) of 2-inch pipe = 0.026 ft^2 x 1 foot
   - = 0.26 ft^3
4. Weight of water in 1 foot of pipe = volume x weight of water per pound
   - Water is 64 lb per ft^3 (conversion factor)
   - Weight = 0.026 ft^3 x 64 lb = 1.664 lbs
5. Total weight per foot of pipe = weight of pipe + weight of water
   - Weight of 1 foot of pipe (empty) = 0.65 lbs (measured)
   - Weight = 1.664 lbs (water)+ 0.65 lbs (pipe) = 2.314 lbs per foot
6. Weight of 20-foot section of 2-inch pipe (filled) = weight per foot x 20 feet
   - Weight = 46.3 lbs
7. Gallons of water in 20-foot section
   - Weight of water in 20-foot section = 33.28 lbs
   - 1 gallon of water = 8 lbs (conversion factor)
   - Gallons = 33.28 lbs ÷ 8 lbs/gal = 4.16 gallons
8. Therefore, a 20-foot section of 2-inch pipe filled with water weighs 46.3 pounds and contains 3.5 gallons of water.

The hydro unit

The hydro system takes water from two stream beds which normally converge, run *west* to the base of the hill, and join a larger streambed at a point more than 400 feet *north* of the house. Fortunately, the terrain was such that I could avoid an extra length of pipe by planning a more direct routing of the pipe track to a point close to the house for easy monitoring, inspection, and adjustment of the hydro unit.

It is prohibitively costly to buy and install electrical wire to carry 12V power between a hydro unit and a house over any large distance. Generally, it is 2-4 times more expensive to run wire than pipe, where there's a choice.

There were two additional benefits to the hydro site I chose in this installation: erosion control and access. The *original* streambed was suffering erosion at the point where it originally entered the large stream. At the chosen site for the hydroturbine, the discharged water entered an existing (different) streambed which ensured that it had a good path back to natural drainage. The culvert for this streambed was in direct line with the more direct routing of the pipe track. By routing the pipe *through* the culvert next to the house, I avoided having to bury the pipe or substitute hanging or buried wires across a courtyard. While these factors are site-specific, they illustrate that a good cost-benefit ratio results from such consideration of the range of factors that do apply at any site.

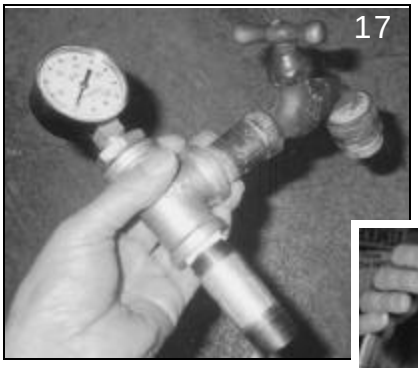
I advised Donna that the hydro unit would produce *some* noise. After some discussion, we agreed to install the hydro unit in a temporary way so she could experience a season with it in such close proximity.

I wanted to take the hydro unit home to finish up some work on it. Nevertheless, I took the time to position it precisely, enabling me to make critical decisions about related topics such as electrical wiring, plumbing, foundation, controls, and weatherproofing.

To this end, I positioned two redwood beams over the dry streambed about 10 feet away from the culvert through which I had routed the last of the pipe track. Set astride these beams, the hydroturbine can safely discharge water without eroding the banks. I used a claw hammer to dig, shape, and level the soil where the beams intersected the bank so they wouldn't slip or roll sideways. If this site proves acceptable, these will be replaced with concrete blocks. I temporarily added shims to the crosspieces to level the hydro unit and aim its intake pipe at the point where the pipe emerged from the culvert.

Once the hydro unit was set in place, I could see how I might bend a thin sheet of clear acrylic plastic over the hydro unit and its control panel and screw its ends into the beams. I figured this would give the alternator the weather protection it needed, provide some noise abatement, *and* spiff up the look of the installed unit, too.

At the point where the pipe track exited the culvert, I installed a 2-inch tee. The tee would accommodate plumbing to mount both a drain valve *and* a pressure gauge (Fig. 17)

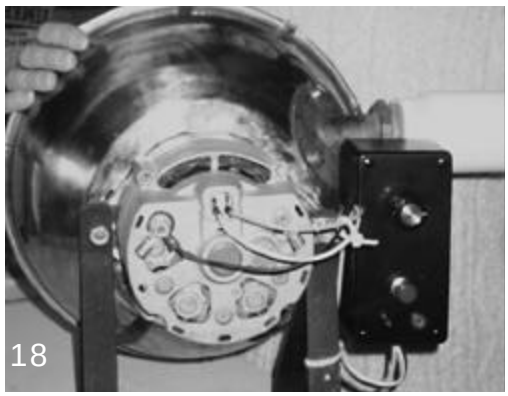


17. A pressure gauge and ¾-inch drain valve are assembled, ready to be added to the pipe track.

Next to the tee, I added a 2-inch, inline ball valve. The 2-inch ball valve was there to turn on (or shut off) water to the hydro unit. Normally, mounting *any* valve low in a hydroelectric system is *not* recommended as it resists the flow of water even when fully open, reducing pressure and power output. Some valve types (alas, the inexpensive ones) are horribly resistive. A gate valve has the least resistance but suffers when sediment fills the bottom inside of the gate's guide. Mounting it vertically would offset this limitation but that wasn't going to work in this layout. I opted for a brass ball valve that rotated through 90° with the lever aligned (parallel) with the pipe when it was open.

I wanted to plumb the ball valve, a drain valve, and the pressure gauge at the culvert's end (instead of the hydro unit) for a good reason. Even in bad weather, Donna would be able to walk up to these controls from the roadbed, read the pressure gauge, shut the water on or off, and even drain the pipe track. I planned to orient the pressure gauge so that its reading would be visible from either the roadside *or* the hydro unit itself.

I took home the hydro unit. Now that I had decided how to weatherproof the hydro unit, I knew where to mount the homebuilt control box for its alternator. I drilled a ¼-inch hole in the side of the control box, bolted a 2-inch angle bracket to its wall, and sandwiched the other end into the



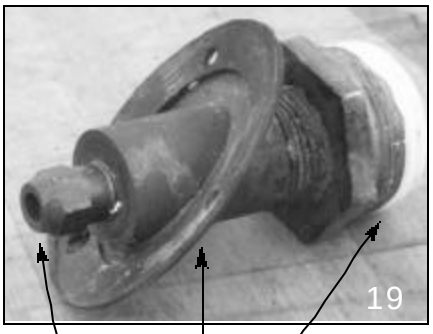
18. The homebuilt control box is bolted and wired to the hydro unit.

support structure for the hydro unit (Fig. 18).

Next, I crimped spade connectors on the wires from the control box and secured them to the alternator's field (F), rotor (R), and B+ terminals. Plastic ties secured these wires together and to the hydro unit's support structure.

My next focus was the nozzle-jet assembly. The hydro unit had been hacksawed out of its previous application and I needed to remove the old fittings and install new ones. Because this unit was mounted to one of the thin aluminum bowls, I unbolted it to avoid warping the thin material while I wrenched off the old couplers. Once it was off, I exchanged old with new couplers. When I began to replace it, I discovered that the holes in the bowl were much larger than the plate which held the nozzle assembly. How would I correctly align the jet to the Pelton wheel? I roughly bore-sighted it (looked through the jet) from the nozzle end as I loosely bolted it up. Then, in a flash of inspiration, I pressed the lens of a flashlight against the new coupler, switched it on, and turned off the shop lights. Sure enough, I was able to keep the jet aligned with the buckets on the Pelton runner while I bolted it tight.

I purchased and installed the fittings that would plumb the hydro unit to the pipe track. Now, I need only install the hydro unit and cut the last segment of pipe track to the correct length to terminate in these fittings.



19. The nozzle-jet assembly is designed to bolt to one of the two aluminum bowls.

20. The beam of a flashlight helped to align the nozzle with the Pelton wheel.

21. New fittings were added to mate the hydro unit to the pipe track.

Electrical wires

There was a measured distance of 75 feet between the hydro unit and the existing system—service panels, controllers, and battery pack. First, I needed to size the wires between the hydro unit and battery pack.

Using a table in one of my books (*Better Use Of*), I noted that a 15A current (i.e., 180W output) transferring 12V electricity a distance of 75 feet would require two #4 wires (5% loss) or two #6 wires (10% loss). I finally opted for #6 wire. My justification? A hydro system is a 24-hour power source, so the 5% of difference in efficiency didn't amount to much power while the #4 wire was more than *twice* the cost of #6 wires.

I purchased 75 feet each of black and white stranded #6 wire. Leaving enough wire at the service entrance, I routed the wire under a large deck, nailing it along a beam with the U-shaped brads used for securing cables.

A narrow, deep trench was dug to extend the wire from the end of the deck to the hydro unit's position. I cut, inserted, and buried a 10-foot section of 1-inch PVC pipe in this trench to route and protect the wires. I then taped the ends of the #6 wires together, along with two strands of smaller wire (for the shunt) of the kind used for doorbells. I pushed these bundled wires through the pipe from the deck end until they emerged at the hydro unit.

Next issue

A week before I was ready to bus up to Gold Beach, Oregon, to lay out this issue, Motherland was blanketed with a few feet of snow and the access road became impassable. So ... this is a good place to stop.

It's just as well. I've designed and constructed the culvert diversion assemblies (which will feed water to the sediment barrel), but they have not been installed. Since these units are highly experimental, I don't want to spend *any* time discussing their construction until I *know* they will work. As well, the seasonal streams are just now beginning to flow somewhat but are not at full strength.

It will be two months before the next issue goes to press. In the interim, I will complete the installation and, nature willing, the water will be of sufficient flow soon to bring the system online.

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