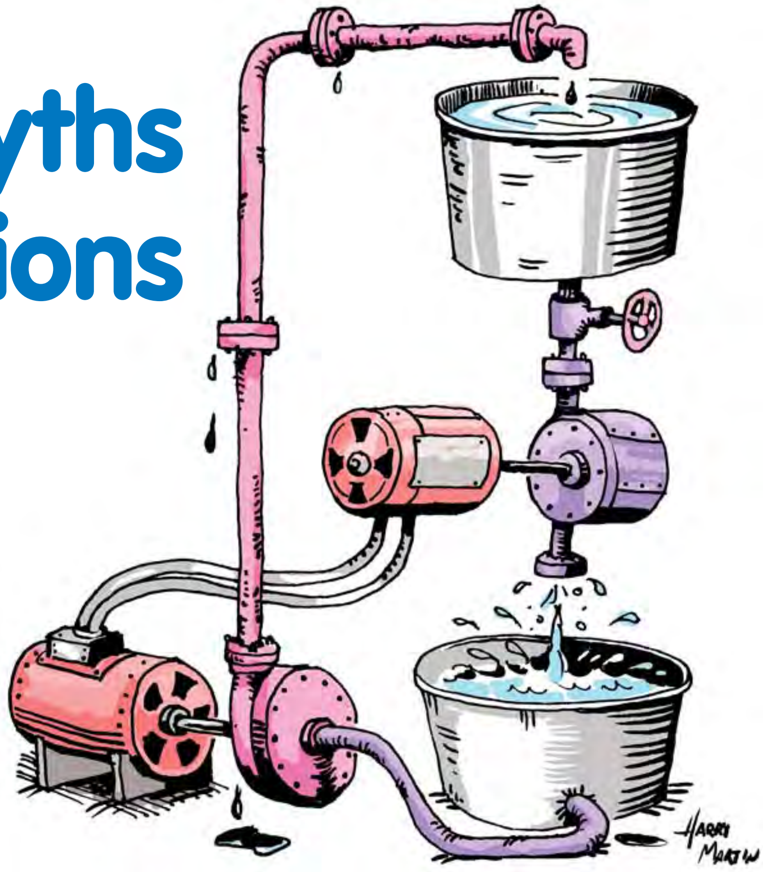
Microhydro Myths & Misconceptions



by Benjamin Root

Making electricity from falling water can seem like magic, and that's led to lots of misconceptions. Here, we'll separate fact from fiction when it comes to what microhydro systems can and cannot do.

Residential-scale microhydro-electric systems have the reputation of being the holy grail of home renewable-energy (RE) systems. While they lack some of the hype, magic, and bling of solar-electric (photovoltaic) systems, microhydro systems are a simple technology that most people can understand…at least in general. In this article, we'll look at some common microhydro system *misconceptions*, most of which come from folks looking for shortcuts to the reward of cheap electricity.

Modern microhydro equipment comes from proven technology based on designs that have changed very little over the decades. Pelton and turgo wheels, the typical spinning water-wheel component, were invented in 1870 and 1919, respectively. The point is, this technology has proven its reliability and functionality with more than a century of performance.

The cost of these systems, and thus the cost of the resulting electricity, also has the reputation for being very reasonable when compared to other renewable or home-generated sources. While PV module prices have recently dropped, they are still a high-tech and expensive commodity. Microhydro systems can arguably be considered *low-tech*, with civil works and pipelines often being the majority of the system cost. Of course, the actual cost varies significantly from site to site, and from system to system.

Another element that keeps microhydro-generated electricity low in cost, and thus high in desirability, is the system's continuous duty cycle. While PV systems only produce electricity when the sun is shining (and wind-electric systems when the wind is blowing), microhydro systems aren't affected by nightfall or weather blocking the sun. Even a small hydro resource can provide electricity 24 hours a day, and often 365 days a year (if the water source is year-round). The bottom line for any renewable energy system is the amount of energy it can produce annually. A low power source working all of the time can often produce a lot more energy than a more powerful source that only works intermittently.

So, why doesn't everyone have a microhydro system? Herein lies the challenge. A viable hydro resource is dependent on the availability of falling water at, or near, the site of the electrical loads. It is the weight or pressure of that flowing water that spins the turbine to produce electrical energy. Not everyone has access to a stream or spring of adequate volume on their property, nor does everyone have the topography to create the vertical drop needed to pressurize that water with gravity. See the "Microhydro Rules" sidebar for a formula about how water flow and vertical pressure (head) combine to determine the power available from a potential hydro site. That site-assessment formula will help debunk some of the myths that follow.

Many microhydro misconceptions are a combination of misunderstanding some of the basic properties of physics, and an overzealous optimism about the potential of RE resources. Here, we hope to correct the misconceptions about physics, while at the same time further encouraging educated optimism. Once you've had a little reality check here, we suggest you read some of *Home Power's* other articles on the basics of hydro site assessment and microhydro systems (see Access at the end of this article). Perhaps you really do have untapped hydro potential waiting for you.

web extra

For more on microhydro systems, see "The Basics" at **www.homepower.com**

Myth 1: Closed-Loop / Pumped Storage

By far, the most common flawed design that we hear about at *Home Power* is the closed-loop system—that is, some scheme to pump water for the hydro turbine, and then have the turbine produce the electrical power for the pump…ad infinitum. Some of these schemes are simple "hydro-in-a-bucket" designs where the pump is expected to pressurize the water for the hydro turbine. Others are more involved, planning to pump water uphill to a pond or tank, and then let gravity do the job of running the turbine. All the while, the designer is expecting to get *extra* usable electric power from the turbine's output—beyond what the pump is using. Whether large or small, all of these designs suffer from the same flaw in thinking.

The first law of thermodynamics says that energy can neither be created nor destroyed. All of the energy systems (renewable and otherwise) that we rely upon *convert* existing energy into a form that we can use to do the work we want to do. In a hydro-electric system, the energy of moving water is transferred to a rotating shaft, converted to changing magnetic fields, and then converted to moving electrons (electricity). But at no point is energy *created.* If we use that energy to create magnetic fields again, spinning a shaft and pumping water up to a tank on a hill, we still haven't created any energy. We've just changed its form again.

In a perfect universe, perhaps it could be argued that such a pump and turbine arrangement could run *perpetually*. But it wouldn't do us any good, because we want to use that electricity to do some work besides just running the pump. Using any electricity for other tasks would be robbing the pump of the power it needed to keep up with the turbine, and the loop's interdependence would break down. That, and the fact that there are always other forces robbing energy from the system, means that such a loop wouldn't run for long, and that *no* additional energy could be extracted from it.

Those additional energy-robbing forces, mostly friction, are the imperfections that cripple this closed-loop design. Every component of such a system has an operating efficiency of less than 100%. That means each conversion step in the process wastes some of the potential energy that the system started with. We know that energy is not being destroyed, but it is being allowed to escape the loop in the form of heat, vibration, and even noise. It is being converted into a form that we can't readily use, or even recover.

Let's look at some typical microhydro system efficiency numbers:

- Penstock (pipeline) efficiency = 95%
- Nozzle and runner efficiency = 80%
- Permanent-magnet alternator efficiency = 90%
- Wiring and control efficiency = 98%

0.95 × 0.80 × 0.90 × 0.98 = 0.67

By the time the water has moved through this example microhydro generator system, only 67% of its initial potential

Microhydro Rules

The instantaneous power available from a microhydro system is based on two main factors:

- The quantity of water (per unit time) moving in a river or stream, and that is available to be diverted through the turbine, is called *flow*. It is expressed as a rate such as cubic feet per second (cfs) or gallons per minute (gpm).
- The pressure that drives that flow is caused by the vertical height between the intake and the turbine. The *head* is basically the weight of that water column and can be expressed as pressure (psi or bar), but is more often discussed in terms of vertical *feet* of head since that relates directly to the topography of the site—2.3 vertical feet of water will create 1 psi.

Together, head and flow are the driving forces that spin the turbine at the bottom of the system. A hydro system designer will use these two measurements to determine the pieces and parts necessary to optimize a system. Intake and turbine locations will be chosen to maximize head, while minimizing pipe and wire runs and other site-specific challenges. Pipe will be sized to balance reducing friction loss with keeping costs in check. The number of nozzles, runner type and size, and alternator size will all be carefully balanced to work with available flows without depleting the source (and ideally, without negatively impacting the local ecology). And the efficiencies (inefficiencies) of each component in the process will be calculated for an accurate estimate of the power available at the site.

But there is a simple formula to guesstimate a site's general hydro potential without going though all of the formulas and variables of turbine choice and pipe sizing:

Head (vertical ft.) × Flow (gpm) ÷ Derate factor = Power (W)

The derate factor is commonly between 9 and 13. This range has been determined over the years from the measured real-world performance of professionally installed hydro systems. A low derate factor like 9 would be appropriate for cases with good head and flow, and relatively short pipe runs and other inefficiencies. Higher derates, like 13, would be for cases where either head or flow (or both) is challengingly low, or other obvious inefficiencies will occur. This factor also takes into account the canceling out of units to arrive at watts; do not try this formula using cfs, psi, or other units of measurement.

In some of the myths in this article, this formula is used to illustrate example scenarios. Because these myths are so fallacious, we can use a nice optimistic 10 as a derate factor. (In fact, with the tiny systems described, the derate might actually be twice that.) Besides making the math easy, you'll find that even giving a myth this benefit of the doubt won't make it stand up to the real tests of physics, financial viability, or both.

You should feel encouraged to use this formula as a starting point in assessing your site's hydro potential. It may help you decide if you should contact a professional system designer, or drop the idea. Besides, the variables you used in the formula will be the first questions that a pro will ask, (so make them accurate). Knowing your site's *measured* head and flow in advance will save everyone time and money. (See "Intro to Hydropower Part 2: Measuring Head & Flow" in *HP104*.)

energy has been converted to electricity. In fact, this would be considered very good performance—typical systems are about 55% efficient.

Now let's consider the efficiencies of pumping that water back to the hydro intake for reuse:

- Pipe efficiency = 95%
- Pump (motor and impeller) efficiency = 65%

0.95 × 0.65 × 0.67 (from above) = 0.41

By the time the water had gone all the way through the system, only 41% of it would be returned to the top of the intake. After a second loop around, only 17% (0.41 × 0.41) of the water would be left.

If there isn't a water supply with useful head and flow to start with, *nothing* will happen—the pump won't run because it won't have electricity; the hydro turbine won't have electricity because the pump isn't running. Adding water (or electricity) to "prime" the loop will make the loop operate only as long as the priming continues.

This is where creative folks start asking questions about bigger water tanks; larger pipes with less friction loss; tanks on a tower for shorter pipe runs; more head, and less flow; less head and more flow; adding batteries (only 80% efficient themselves); or even just piping right from the pump to the turbine—anything to improve system efficiency. In fact, the simplest thing that could be done to get rid of inefficiencies would be to skip the water components altogether; just hook the shaft of a motor directly to the shaft of the alternator, and the alternators output wires directly to the motor (somehow, the fallacy in that thinking is easier for us to understand). But no matter the variables, the outcome will be the same—total efficiency will be less than 100% and no energy will be gained.

Utility-Scale Pumped Storage

Utility-scale hydropower facilities *do* pump water uphill. But their goal is not so much to gain or create more energy as it is to reduce overall losses. The utility grid needs to be able to provide power on demand, but its power plants (coal, natural gas, nuclear, and hydro) are slow to come online or take offline. And solar and wind facilities sometimes make power when it's not needed. To meet changing customer needs, plants are often running "in wait," with nowhere to send that power—that energy is potentially wasted. Hydro facilities can divert that unused power to pumping water back to the top of the hydro dam, where the potential energy can be stored for use when loads on the utility grid surge again. The reservoir is used like a giant battery for grid energy. And while efficiencies on that pumping are 70% to 85% (a 15% to 30% net loss), that's a lot better than wasting *all* of the excess power of idling power plants.

Moving energy around and changing its form, like from chemical to mechanical to electrical, is only a way to lose some of it. These efficiency losses are part of the price we pay to get energy into a format that we *can* use. We can lose more, or we can lose less, but adding complexity is inefficiency and will never result in a net gain.

Myth 2: Rooftop / Downspout Hydro

A second common microhydro-electric scheme that we are often asked about is the viability of putting turbines on a home's gutter downspouts to generate electricity from the rain. Some imaginative folks know enough about hydro to understand that the energy has to come from somewhere (in this case, from the forces of nature), and that the height of the roof can contribute head (pressure) to spin that turbine.

The mistake in this scenario is a simple and honest one of scale. While some hydro units have been designed that can function on low head, such as from the roofline of typical homes (and even lower), a hydro turbine's power output is a product of head *times* flow. And it is a lack of significant flow that is the defeating factor in the power equation when relying on rooftop rainwater collection. The watershed drainages for even small streams are usually measured in thousands of acres or square miles. Home roofs, even big ones, are measured in mere thousands of square feet.

Let's look at example calculations for a large house in a very rainy place—Seattle, Washington, gets about 40 inches of rain per year, with November being the rainiest month at an average of about 6 inches.

Let's assume that a tall two-story house would give us a 25-foot-high roof, and thus 25 feet of head. This 6,000-square-foot home has about 3,000 square feet of rainwater collection area (remember, it's two stories). That means that in November, this house would receive about 1,500 cubic feet of rain, or 11,220 gallons.

If that rainfall came as a constant drizzle all month long, flow from the roof would be only about $^{1}/_{4}$ gallon per minute. Currently there is no turbine on the market to work with that flows that low, but using our microhydro power formula (see sidebar), we could theoretically get 468 watt-hours that month.

0.26 gpm × 25 feet ÷ 10 derate = 0.65 watts × 720 hrs./mo.
= 468 Wh

So even if there was a nanohydro plant that could harvest that small flow, it would result in less than $^{1}/_{2}$ kWh of electricity—per month!—and only 3 cents worth of electricity in Seattle. It's a tiny fraction of what even an energy-efficient, 6,000-square-foot home would use in a day, not to mention a whole month.

Would the available energy increase if we weren't dealing with a constant drizzle? What if, to increase flows to a usable rate, and hopefully increase viable energy production, we could hope that all that rain came in a great deluge of 1 inch per hour (a 100-year storm, in Seattle) over six hours! At that unlikely amount of rain—practically all at once—flow from our example roof would be about 31 gpm. That is a more viable flow rate for hydro turbines on the market and gives us a projected power production of 77.5 watts, but only for those six hours. The total of 465 Wh per month is about the same energy as the drizzly example above (the minor difference is from rounding significant digits).

This is when inventive thinkers will begin planning for taller homes, or additional rain-collecting roof areas, and tanks to hold the water for release all at once to increase flow. But even that 11,220 gallons of water that falls on our 3,000-square-foot roof that month would weigh almost 47 tons if stored. Imagine a structure at roof level capable of supporting that kind of load just to generate a minuscule amount of energy. And remember, these discouraging energy production numbers are for the rainiest month, in one of America's rainiest cities. Other months, other places, and smaller houses can only deliver worse performance.

In this case, it would be better to just spend the money on a PV system. To put things into perspective, even in Seattle, which gets only an average of 1.7 peak sun-hours per day in November, an inexpensive (less than $100) 15-watt PV module would make close to the same amount of energy as the proposed rooftop hydro system.

Myth 3: Hydro from Municipal Water Supply

So, a thinking person might begin wondering where they could get good water pressure and adequate flow necessary to run a microhydro turbine. It's the kind of question an inspired hydro wannabe might ponder, say, while standing in the shower. And that's when another common hydro scheme is hatched.

Typical municipal water pressure is between 40 and 80 psi, the equivalent of 92 to 185 feet of head. That is definitely enough for a hydro system. And if available flow is about 10 gallons per minute, say at the bathtub faucet, then surely there must be some real power available whenever we turn on our faucets.

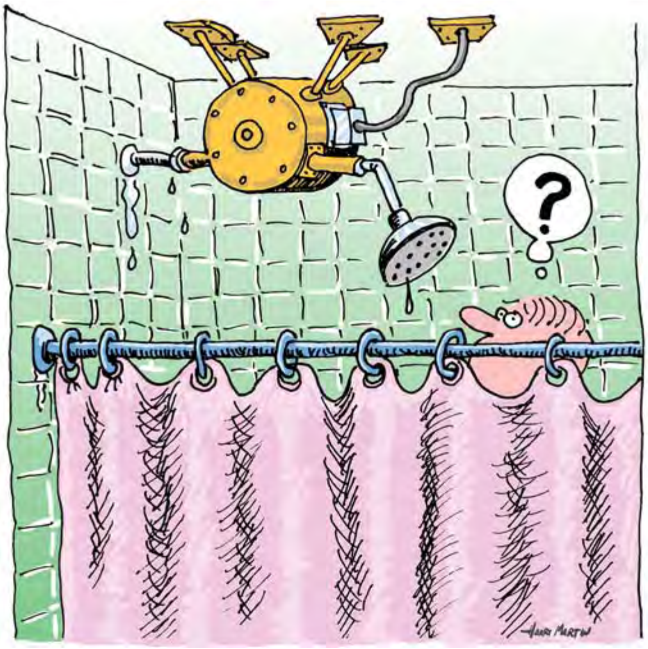
However, if we use our example power formula with a common pressure of 60 psi (138 feet), we get a projected power output of about 138 watts.

138 ft. × 10 gpm ÷ 10 derate = 138 W × 24 hrs.
= 3,312 Wh per day

That 3.3 kWh per day is something—but not a lot. An *average* American household uses about 30 kWh per day, so would need nine of these units.

For the sake of argument, let's assume a very energy-efficient home that could run on 3.3 kWh per day. Why not then use such a hydro system? Or, why not offset a portion of a home's loads with hydro? Every little bit helps, right?

The 3.3 kWh figure is based on using 10 gallons per minute—*24 hours per day*. That's 14,400 gallons per day. At an average cost in the United States of $1.50 per 1,000 gallons, that's $21.60 per day in water costs just to generate 36 cents worth of electricity (based on the U.S. average of $0.11 per kWh).



Then there is the ecological and moral impact—remember, this is water that has been treated and purified for human consumption, and uses pumps to maintain that pressure—processes likely paid for in part with taxpayer money. Costs aside, what are the implications of pouring good clean water down the drain just to make a little electricity?

Finally, just to add a final coup de grâce to this hydro scheme, remember that most of what we do with our domestic water requires water pressure, as well as flow, to get the job done. Taking the energy out of water to make electricity robs that water of its pressure—water merely falls dead (depleted of energy) out the bottom of a hydro turbine. And pressure at other faucets may be anemic at best—imagine trying to rinse shampoo out of your hair while a hydro system is running full-bore in the same home. Not so effective, or enjoyable.

Myth 4: Reducing Pipe Size to Increase Pressure / Power

There is no substitution for head and flow in an effective microhydro system. When head is inadequate, we begin to think of creative ways to increase pressure. The simple example of watering the garden with a hose comes to mind. Doesn't putting your thumb partially over the hose opening increase the pressure, shooting water farther across the lawn? What if you use a spray nozzle instead of your thumb? Didn't you just increase the power of that system by reducing the size of the nozzle? And therefore, couldn't you increase head (and thus power) in a hydro system by starting off with a large pipe diameter and then reducing the pipe size on the way to the turbine?

Sorry, but no. When a pro measures head in a hydro system, they note two different types. Static head is the pressure at the turbine with the bottom valve closed, and thus no water moving. It is the pressure, from the weight of all the water in the pipe above the turbine. This pressure, measured in pounds per square inch (psi), is in direct proportion to the height of that column of water. For every 2.3 feet of vertical head, you'll measure 1 psi. Because it is directly proportional, there's no need to put in pipes and fill them with water to measure it; just measuring the vertical drop between water source and turbine site will give you an accurate static head.

But static head is just a maximum starting point. Dynamic head is the adjusted theoretical pressure in the system when inefficiencies like friction loss of pipes, joints, elbows, and valves are considered. These things hinder the flow of water through the system, and therefore some of its potential energy. Dynamic head is the result of static head minus these power losses, and provides a more accurate estimate of turbine performance.

Adding a smaller pipe section or nozzle is basically adding another restriction in the pipe that creates resistance to the flow of water. It effectively lowers the dynamic head of the system and thus also lowers the total power available in the system.

"Wait," you say, "what about the hose spraying farther across the yard?" Or maybe you are savvy enough about hydro systems to know that impulse turbines actually use nozzles to shoot a stream of water at the spinning runner. Well, you are right, but neither pressure nor power are being *increased* by the nozzle. Instead, the existing energy is being concentrated into a smaller point and at higher velocity—which is a more usable form for the turbine—but, in the process, some of that energy is lost to friction.

The purpose of a nozzle is to increase the kinetic energy of the flowing water by increasing its velocity. But this is at the expense of its potential energy in the form of pressure. In fact, on the outlet side of a nozzle, there is no pressure in the water; it is carrying all of its energy in the form of fast-moving kinetic energy. And it is the force of this kinetic energy against the turbine's runner that makes it spin. But no increase in energy was created. In fact, that water moving faster through a nozzle has more friction loss, reducing our dynamic head and total available power in the system—less power, but in a more useful form.

There is never any more power available than the theoretical maximum based on the initial static head (at a given flow). Every component and change in the form of energy in the system acts as an inefficiency, reducing actual available power. Some of those losses are necessary ones (getting the water down the hill, shooting it at the runner, etc.). Good design can reduce losses, but they can never be eliminated completely. And they definitely can't be changed to net gains.

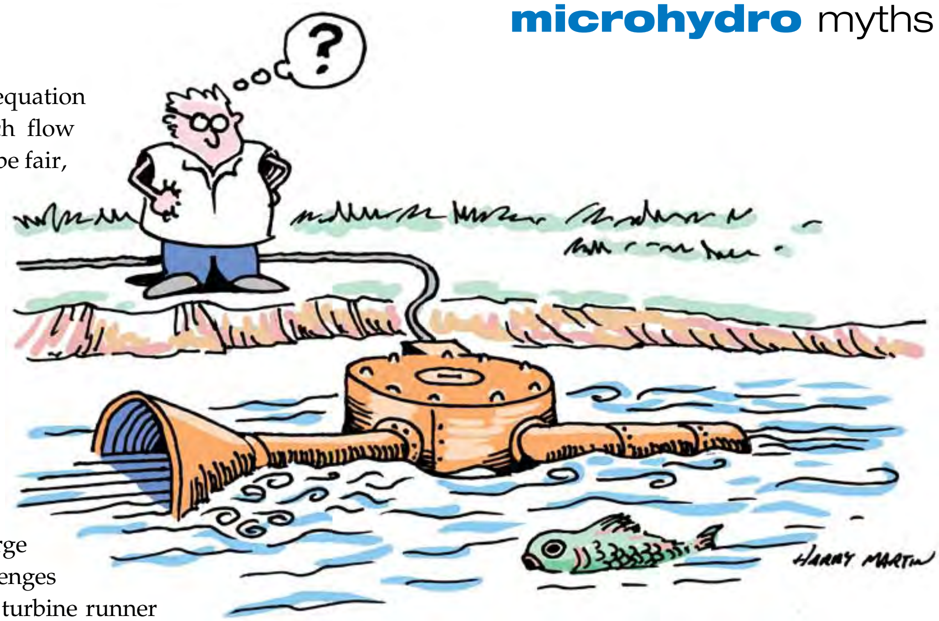
Myth 5: In-Flow / No-Head Systems

It's starting to sound like only those folks with a stream or river on their property have a viable hydro system. But if you do have a good-flowing stream, you're all set for hydro power, right? Well, it's even more complicated than that.

We know that the power available to typical hydro turbines is a product of the head (pressure) and flow rate. So we also know that as head decreases, flow must increase to make the same amount of power. But what about folks with a nice river flowing along relatively flat ground? There must be some energy available in that strongly moving mass of water, even though it isn't falling from a height, right? Well, yes and no.

Besides just turbine size, there are different turbine technologies designed to take advantage of the ratios of head-to-flow at a given hydro site. But as head decreases, the energy gets harder and harder to capture. Reaction turbines, designed for low heads (as low as 2 or 3 feet) spin inside a column of falling water, but need high flow for significant power.

But what about situations with basically no head at all? What about that big river flowing through a flat plain? Well,



try putting zero head into our hydro power equation and you will find that, no matter how much flow there is, the power output will be zero, too. To be fair, there must be some head for the water in a stream to be moving at all, and thus there must be some power there to capture. But even though the movement of that flat-water stream looks enticing, there isn't much potential to start with, compared to the same water dropping down a hillside. And then there's the challenge in capturing it.

To make up for lack of head, flow would need to be substantial. Either the river must be flowing very fast, and/or a very large area of river must be captured. Both create challenges in the integrity of the mounting structure and turbine runner itself, plus the added danger from river debris.

A fast-moving river is often only moving fast in the center. Near the banks, shallows, or along the bottom, friction reduces the flow. The speed of the river in the center can't necessarily be extrapolated to the whole cross-sectional area. Instead, there are specific formulas to account for the reduced flow along the bottom and shallow sides of a stream.

And even a quickly flowing river is moving a lot more slowly than the runner in a jet-driven impulse turbine in a system with higher head. A slowly spinning runner needs to be geared to create the rotational speeds necessary to generate electricity with an alternator. The gearing adds further complexity and friction loss to the system—more inefficiency.

We're not saying that it can't be done. But we are saying that it's unlikely that you can buy anything off the shelf that will do an adequate job for you. There have been, and will continue to be, many inventions intended to capture energy from the flow in a river. These "in-flow" or "current turbine" designs come and go, and come again, but we rarely see anything that performs to a level that warrants a reliable consumer product. There are a couple of in-flow products on the market (Ampair and Jackrabbit) that were originally designed for towing behind sailboats or barges. Some have adapted these to use in streams, but the small swept area of their propeller requires high-velocity flow to make much usable power.

If you are a tinkerer, and enjoy the creative challenge of hydro design, you may be able to fashion an in-flow turbine to make some power (though it may never pay back financially). But if you are being tempted by commercially available in-flow turbine designs, caveat emptor. Do your homework by talking to other reputable hydro installers about your resource and options. Be realistic about your capturable stream area and flow rate. And ask for real-number data, and references, from the turbine manufacturer.

Head & Flow: Check Your Reality

While microhydro power is a reliable and proven technology, often at a reasonable cost, it's completely dependent on the resources available on a site-by-site basis. Either your site has reasonable hydro potential, or it doesn't. And it all depends on the quantities of head and flow. There's no cheating the laws of physics. There is no way to *create* energy. There is no free lunch.

That doesn't mean that there aren't ways to optimize your hydro potential to get the most energy out of your resource. That's where professional designers and reputable manufacturers come in. They have the knowledge to make decisions on siting and equipment that will maximize the energy made from the head and flow that is available. Intake type, pipe sizing and routing, the size and number of nozzles, runner type, alternator size and type, controller type, and system voltage are all variables that, when combined properly, will make or break your system performance and financial viability.

So give up on the free energy designs. Instead, read some of *Home Power's* real-world articles on hydro system design, do a preliminary measurement of your stream's actual head and flow, and call a reputable microhydro professional. That's the best scheme for maximizing your hydro system's performance.

Access

Benjamin Root is no expert on microhydro power, but with 15 years on staff with *Home Power*, he has seen a frustrating repetition of misconceptions about renewable energy's potential…and hydro seems to take the brunt. Before you try to debunk Ben's debunking, he suggests you do the same thorough research that he did to write this article.

Related microhydro articles in *Home Power*: *HP103*, *104*, *105*, *117*, *124*, *125*, *126*, *132*, *136*