
# An Introduction to Hydropower Concepts and Planning

A publication of Canyon Hydro

# Guide to Hydropower

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# Welcome!

Canyon Hydro has developed this *Guide to Hydro Power* to help you gain a basic understanding of how "home power" micro-hydro systems work, and what goes into the design. We've tried to keep the content objective and hype-free, so you won't see information about Canyon Hydro systems specifically. (But we do hope you keep us in mind when you're ready to buy your hydro system.)

If you're just starting out, we think you will find this information extremely helpful. If you're already a senior hydro engineer, you may be more interested in Canyon's Utility/IPP Systems.

We've divided our *Guide to Hydro Power* into three major sections:

- ***Hydro Systems Overview***, a discussion of how hydro power works, and a look at the major components that make up a hydro system.
- ***Planning Your Own Hydro System***, including how to measure Head and Flow, adjusting for pipeline losses, and computing power output.
- ***Evaluating Turbine Systems and Suppliers***, including tips for evaluating quality, reliability and customer service.

You won't learn everything you need to know to design your own system, but our engineers will be happy to help you when you're ready. All we ask is that you have accurate measurements of your Head and Flow, and we'll take it from there. This *Guide* will show you how.

I hope you find this information useful. If you have comments or suggestions about the content within this *Guide*, please let us know at feedback@canyonhydro.com.

Daniel A. New

President

# Part 1: Hydro Systems Overview

## How Water Power Works

Water power is the combination of HEAD and FLOW.

Consider a typical hydro system. Water is diverted from a stream into a pipeline, where it is carried downhill and through the turbine (FLOW). The vertical drop (HEAD) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that that drives the turbine. More FLOW, or more HEAD, produces more power.

**HEAD and FLOW are the two most important things you need to know about your site.** You must have these measurements before you can seriously discuss your project, the power it will generate, or the cost of components. As you will see, every aspect of a hydro system revolves around Head and Flow. Remember:

- **HEAD is water *pressure*,** which is created by the difference in elevation between the water intake and the turbine. HEAD can be expressed as vertical distance (feet or meters), or as pressure, such as pounds per square inch (psi).
  - ***Net Head*** is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water is turned off. As we'll discuss later, pipeline diameter has a major effect on Net Head.
- **FLOW is water *quantity*,** and is expressed as "volume per second or minute" such as gallons per minute (gpm), cubic feet per second (cfs) or liters per second (lps). *Both* HEAD and FLOW must be present to produce water power.
  - ***Design Flow*** is the maximum FLOW for which your hydro system is designed. It will be less than the maximum Flow of your stream (especially during rainy season), and is often a balance between power output and cost.

Net HEAD and Design FLOW are used to specify hydro system components.

The importance of accurate Head and Flow measurements cannot be overemphasized. Later in this Guide, we'll discuss How to Measure Head and Flow.

### Power Conversion & Efficiency

In reality, the generation of electricity is simply the conversion of one form of power to another. The turbine converts water power into rotational power at its shaft, which is then converted to electrical power by the generator. It is important to note:

- *Power is never created*; it can only be converted from one form to another
- Some of the power will be lost through friction at every point of conversion. *Efficiency* is the measure of how much energy is actually converted.

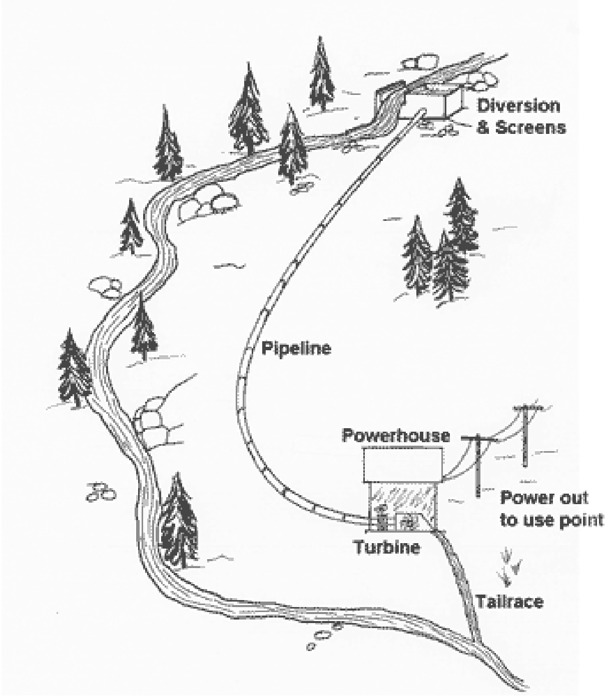
The simple formula for this is:

Net Power = Gross Power x Efficiency

While some power losses are inevitable as water power gets converted to electricity, they can be minimized with good design. Each aspect of your hydro system, from water intake to turbine-generator alignment, affects efficiency. Turbine design is especially important; a good turbine supplier will work closely with you to specify a turbine with dynamic operating characteristics that match your Head and Flow.

## Major Components of a Hydro System

A hydro system is a series of interconnected components: water flows in one end, and electricity comes out the other. This section provides a high-level overview of these components, from the water source to voltage and frequency controls.




*Major components of a hydro system include a water diversion, pipeline to create pressure, turbine & generator, tailrace for exiting water, and transmission wires.*

### Water Diversion (Intake)

The intake is typically the highest point of your hydro system, where water is diverted from the stream into the pipeline that feeds your turbine. In many cases a small dam is used to divert the water. (In most large hydro projects, the dam also creates the HEAD necessary to drive the turbine.)

A water diversion system serves two primary purposes. The first is to provide a deep enough pool of water to create a smooth, air-free inlet to your pipeline. (Air reduces horsepower and can cause damage to your turbine.) The second is to remove dirt and debris. Screens can help stop larger debris such as leaves and limbs, while an area of "quiet water" will allow dirt and other sediment to settle to the bottom before entering your pipeline. This helps reduce abrasive wear on your turbine.

### Pipeline (Penstock)

The pipeline, sometimes called the *penstock*, is responsible for not only moving water to your turbine, but is also the enclosure that creates Head pressure with increasing vertical drop. In effect, the pipeline focuses all the water power at the bottom of the pipe where your turbine will connect. In contrast, an open stream dissipates the energy as it travels down the hill.

Pipeline diameter, length, and routing all affect efficiency, and there are guidelines for matching the size of your pipeline to the Design FLOW of your system. As you'll see later, a small-diameter pipeline can considerably reduce your available horsepower, even though it can carry all available water. Larger diameter pipelines create less friction as the water travels through.

*This stainless steel intake system includes a self-cleaning screen.*

### Powerhouse

The powerhouse is simply a building that houses your turbine, generator and controls. Proper design significantly affects system efficiency, however, especially with regard to how the water enters and exits your turbine.

# Turbines and Efficiency

## Turbine

The turbine is the heart of the hydro system, where water power is converted into the rotational force that drives the generator. It is arguably the most important component in the system, because its efficiency determines how much electricity is generated.

There are many different types of turbines, and proper selection requires considerable expertise. A Pelton design, for example, works best with high Head. A Crossflow design works better with low Head but high Flow. Likewise, other turbine types such as Francis, Turgo and Kaplan, each have optimum applications.

Turbines fall into one of two major types:

- ***Reaction turbines*** run fully immersed in water, and are typically used in low-Head (pressure) systems with high Flow. Examples include *Francis*, *Propeller* and *Kaplan*.
- ***Impulse turbines*** operate in air, driven by one or more high-velocity jets of water. Impulse turbines are typically used with high-Head systems and use nozzles to produce the high-velocity jets. Examples include *Pelton* and *Turgo*.

  A special case is the *Crossflow* turbine. Although technically classified as an Impulse turbine because it is not entirely immersed in water, it is used in low-Head, high-Flow systems. The water passes through a large, rectangular opening to drive the turbine blades, in contrast to the small, high-pressure jets used for Pelton and Turgo turbines.

*Pelton-type impulse turbine with housing cover removed.*

### *Turbine Efficiency*

Regardless of the turbine type, efficiency is in the details. Each turbine type can be designed to meet vastly different requirements, and minor differences in specifications can significantly impact power transfer efficiency.

The turbine system is designed around Net Head and Design Flow. Net Head is the pressure available to the turbine when water is flowing (more on this later), and Design Flow is the maximum amount of Flow the hydro system is designed to accommodate. These criteria not only influence which type of turbine to use, but are critical to the design of the entire turbine system.

Minor differences in specifications can significantly impact power transfer efficiency. The diameter of the runner (the rotating portion), front and back curvatures of its buckets or blades, casting materials, nozzle (if used), turbine housing, and quality of components all have a major affect on efficiency and reliability.

The turbine runs most efficiently when it turns exactly fast enough to consume all the energy of the water. In turn, the water must enter the turbine at a specific velocity (typically measured in feet or meters per second) to maximize efficiency at this RPM. This velocity is determined by Head pressure.

### *Optimizing Water Velocity*

Since power is a combination of HEAD and FLOW, it's easy to see how a larger orifice that moves more water (Flow) at the same velocity could generate more electricity. Conversely, as Flow drops off in the dry season, the orifice must be made smaller to maintain the same optimum velocity for efficient power transfer.

*This needle nozzle provides infinitely variable adjustments to accommodate changes in Flow.*

Keep in mind that turbine speed is not wholly dependent on water velocity; the turbine will turn at a constant speed because it is directly coupled to the generator, where a Governor is maintaining stable RPM by controlling the load. But as the disparity between actual and optimum water velocity grows, less of the energy from the water is transferred to the turbine. The correct orifice ensures the system is operating at its most efficient level.

Impulse turbines (such as a Pelton) are often equipped with a variety of fixed-orifice nozzles that can be used to accommodate changes in Flow. A disadvantage of a fixed nozzle is that the turbine must be shut down to make changes. A popular option is the adjustable needle nozzle, which allows on-the-fly changes with an infinite number of settings.

If you know your Head and Flow, your turbine supplier should be able to make specific recommendations for a turbine system and provide a close estimation of efficiency.

## Drive System

The drive system couples the turbine to the generator. At one end, it allows the turbine to spin at its optimum RPM. At the other, it drives the generator at the RPM that produces correct voltage and frequency.

The most efficient and reliable drive system is a direct, 1:1 coupling between the turbine and generator. This is possible for many sites, but not for all Head and Flow combinations. In many situations it is necessary to adjust the transfer ratio so that both turbine and generator run at their optimum, but different, speeds.

These types of drive systems can use either gears, or pulley and belts, all of which introduce additional efficiency losses into the system. Belt systems tend to be more popular because of their lower cost. Your turbine manufacturer can provide valuable guidance about matching turbine and generator RPM, and suggest options if a direct, 1:1 coupling is not possible.

*Belt drive coupling between turbine and generator.*

## Generator

The generator converts the rotational power from the turbine shaft into electrical power.  Efficiency is important at this stage too, but most modern, well-built generators deliver good efficiency.

There can be big differences in the type of power generated, however.  DC (Direct Current) generators can be used with very small systems, but typically are augmented with batteries and inverters for converting the power into the AC (Alternating Current) power required by most appliances.

AC generators are normally used in all but the smallest systems.  Common household units generate 120VAC (volts AC) and 240VAC, which can be used directly for appliances, heaters, lights, etc.  AC voltage is also easily changed using transformers, which makes it relatively simple to drive other types of devices or transmit over long distances.   Depending on your power requirements, you can choose either single-phase or three-phase AC generators in a variety of voltages.

One critical aspect of AC power is *frequency*, typically measured as cycles per second (cps) or Hertz (Hz).  Most household appliances and motors run on either 50Hz or 60Hz (depending on where you are in the world), as do the major grids that interconnect large power generating stations.  Frequency is determined by the rotational speed of the generator shaft; faster rotation generates a higher frequency.

# System Control

## Governors and Controls

Governors and other controls help ensure that the generator constantly spins at its correct speed. The most common types of governors for small hydro systems accomplish this by managing the *load* on the generator.

To illustrate, consider a hydro system without a governor. When you increase the load on the generator by switching something on, it causes the generator to work harder. Without a governor, it would slow down, lowering both voltage and frequency. Likewise, removing a load by switching something off would cause the generator to speed up, raising voltage and frequency.

With no load whatsoever, the generator would "freewheel," and run at a very high RPM (possibly causing damage). But by adding progressively higher loads, you would eventually slow the generator until it reached the exact RPM for proper voltage and frequency. As long as you maintain this "perfect" load, known as *Design Load*, power output will be correct. (Design Load is based on Design Flow. When Flow drops off during dry periods, the load on your generator will need to be reduced as well.)

You might be able to maintain the correct load yourself by manually switching devices on and off, but a governor can do a better job – automatically.

## Electronic Load Governors

An electronic load governor works by automatically adjusting the load so the generator always turns at exactly the right speed. In effect, it is always slowing the generator down just enough to produce correct voltage and frequency.

*In addition to managing ballast loads, this Load Management Governor can prioritize up to 8 additional devices.*

Electronic load governors constantly monitor voltage or frequency, adding or subtracting electrical loads as necessary to compensate for human usage. For example, let's say our system has a Design Load of 5kW. To maintain proper voltage and frequency, power consumption from the system must *always* be 5,000 watts. If a person switches off a 1,500 watt stovetop burner, the governor will sense the rising frequency and compensate by switching on a different 1,500 watt load (such as a baseboard heater) to maintain total load at 5kW.

In this example, the governor must have direct control over 5,000 watts of load, so that it can provide total Design Load in the event all human-controlled loads are switched off. Moreover, it must be able to control loads in small increments (perhaps 100 watts) to compensate for light bulbs, small appliances, etc. to keep the frequency exact.

An electronic load governor is highly effective for small systems up to about 12kW. It uses two or more "ballast" loads, which can be any purely resistive device such as a heater. Excess power is shunted to the ballast loads, and a variable electronic switch can regulate the amount of power being directed to the ballast (much as a dimmer switch can regulate power to a light bulb). In this way, the electronic governor can make small-wattage adjustments even though the ballast loads themselves may be quite large.

## Load Management Systems

A load management system is an enhanced version of the electronic load governor, offering not only the ability to regulate power usage, but also the option for you to choose and prioritize how power is used. In addition to the ballast loads described above, it can directly control a wide variety of devices via relays.

Small load adjustments work just like the electronic governor; the variable electronic switch regulates power to the ballast loads. When there is enough excess power, however, the load management system will control other devices in a certain priority.

For example, let's assume you've connected two water heaters and a room heater to your load management system. Excess power is directed first to the top priority load, your primary water heater. If there is still excess power available, it will be directed to your next priority, the room heater. If still more power is available, it will go to your backup water heater.

Now assume your well pump kicks on. It draws significant power, but probably runs for less than a minute. Power to one of the water or space heaters may be briefly interrupted while the well pump runs, and then restored when it shuts off. Obviously the brief interruption won't have a major impact on the availability of hot water or room temperature, and the well pump always has power when it needs it.

Similarly, water in your primary water heater will eventually get hot and the thermostat will switch off. The load management system will automatically compensate, moving down the priority chain until it finds a load it can turn on. Load management systems typically have six or more loads that can be prioritized and switched using relays, and their seamless operation helps facilitate normal household activities, even with relatively small hydro systems.

## Emergency System Shutdown

An emergency shutdown system is an option that protects the system from overspeed, which may damage the generator. For example, if a tree falls over a power line, it may cause either a dead short (an extremely high load on the generator) or an open line (zero load) which would cause generator runaway. (A dead short may also cause runaway if it trips a breaker.) Any of these conditions are both dangerous and expensive, so an emergency shutdown system is a wise investment.

*Close-up of jet deflector in position to deflect the water jet away from the turbine.*

Emergency shutdown usually means removing all water power from your turbine. It is important to recognize, however, that an abrupt halt to water flow could damage your pipeline. (If you've heard your plumbing "bang" when you've turned off a faucet, you get the idea.) For high-flow turbines such as Francis and Crossflow designs, water flow must be reduced gradually.

Emergency shutdown of impulse turbines, such as Pelton and Turgo designs, can be very fast because the water jet can simply be deflected away from the turbine. Since the water flow doesn't change, there are no damaging surges.

There are many different techniques for managing overspeed conditions, not all of which require an emergency shutdown device. Check with your turbine supplier to see which approach would be appropriate for your hydro system.

## Utility Grid Interface Controls

Utility Grid connections are becoming more commonplace, but proper controls are essential for proper operation and – above all – safety.

The grid interconnects very large, public utility power generation systems. It allows hundreds of megawatts of power to move around the country as regional supply and demand change. It provides automatic controls and switchgear, so that a failure in one location can be bypassed with minimal impact to consumers. Most of the time the grid works well, but as illustrated with the widespread U.S. power outage of 2003, it can be remarkably fragile as well.

It is possible to interconnect a small hydro system with the utility grid. Grid connection would allow you to draw power from the grid during peak usage times when your hydro system can't keep up, and feed excess power back into the grid when your usage is low. If you choose to do so, however, keep in mind that significant synchronization and safeguards must be in place.

Grid interconnection controls do both. They will monitor the grid and ensure your system is generating compatible voltage, frequency, and phase. They will also instantly disconnect from the grid if major fluctuations occur on either end.

Automatic disconnection is critical to the safety of all parties. For example, if a tree falls on a public utility line, their grid controls will automatically shut down that portion of the line. But imagine if your hydro system continued to send power to the downed line. When the public utility line crew shows up to repair what they believe is an inactivated line, they could be in grave danger. You could face the same danger if you were unaware the grid was powering your lines.

If you are thinking about connecting to the utility grid, begin by contacting your utility company to learn their policies. If you expect to sell power back to the utility, pay extra attention to the efficiency of your hydro system, because higher output and a lower cost-per-watt will go straight to your bottom line. Your turbine manufacturer can give you guidance on the most efficient design, as well as grid interconnection controls and safeguards.

# Part 2: Planning Your Own Hydro System

Now that you have a basic understanding of hydro system components, it's time to begin assessing your own hydro power potential.

## The Four Things You Need to Know

Before you can begin planning your systems or estimating how much power you'll produce, you'll need to make four essential measurements:

1. Head (the vertical distance between your intake and turbine)
2. Flow (how much water comes down the stream)
3. Pipeline (Penstock) length
4. Transmission Line length

In this section, we'll discuss how to make these measurements and how they affect the design and efficiency of your hydro system.

## Measuring Head and Flow

HEAD and FLOW are the two most important facts you need to know about your site. You simply cannot move forward without these measurements.

Your Head and Flow will determine *everything* about your hydro system – pipeline size, turbine type, rotational speed, generator size – everything. Even rough cost estimates will be impossible until you've measured Head and Flow.

Also keep in mind that accuracy is important. Unless your measurements are accurate, you could end up with a hydro system designed to the wrong specs, producing less power at a higher cost-per-watt than would otherwise be possible.

### Measuring Head

HEAD is pressure, created by the difference in elevation between the intake of your pipeline, and your water turbine. Head can be measured as vertical distance (feet or meters) or as pressure (pounds per square inch, newtons per square meter, etc.). Regardless of the size of your stream, higher HEAD will produce greater pressure – and therefore power – at the turbine.

The following conversions may be helpful:

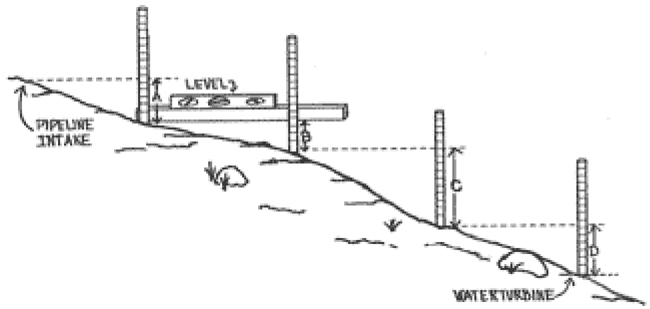
- 1 vertical foot = 0.433 pounds per square inch (psi) pressure
- 1 psi = 2.31 vertical feet

*Accuracy is critical* when measuring HEAD. It not only affects power, but also determines the type of turbine to use (such as a Francis or Pelton design), as well as the hydrodynamic design of the turbine buckets or blades. An altimeter can be useful in estimating Head for preliminary site evaluation, but should not be used for the final measurement. It is quite common for low-cost barometric altimeters to reflect errors of 150 feet or more, even when calibrated. GPS altimeters are often even less accurate.

There are two accurate methods for measuring HEAD: direct distance measurement, and water pressure.

### Direct Distance Measurement

You can use a surveyor's transit, a contractor's level on a tripod, or a level taped to a straight board to measure head. You will also require a pole with graduated measurements. (A measuring tape affixed to a 20' section of PVC pipe works well.) Direct measurement requires an assistant.




Make a series of vertical measurements using the transit level and the vertical measuring pole. Make sure each transit setup is exactly level, and ensure the measuring pole is vertical. Keep detailed notes at each step, and then add up the series of measurements (A,B,C,D,etc.) to find total HEAD.

### Water Pressure Measurement

If the distance is short enough, you can use one or more garden hoses to measure Head. This method relies on the constant that each *vertical* foot of HEAD creates 0.433 psi of water pressure. (10 vertical feet would create 4.33 psi.) By measuring the pressure in the hose, you can calculate the elevation change of your system.

Run the hose (or hoses) from your proposed intake site to your proposed turbine location. If you attach multiple hoses together, ensure each connection is tight and leak-free. Attach an accurate pressure meter to the bottom end of the hose and completely fill the hose with water. Make *sure* there are no high spots in the hose that could trap air.

If necessary, you can measure total HEAD over longer distances by moving the hose(s) and taking multiple readings. Keep in mind, however, that there is less than a half-psi difference for every vertical foot. Except for very steep hillsides, even a hundred foot hose may drop only a few vertical feet. The chance for error significantly increases with a series of low-Head readings. Use the longest possible hose, along with a highly accurate pressure meter, to measure HEAD. The pressure meter must be graduated so that measurements are taken in the middle of the pressure gauge's range. Don't use a 0 - 800 PSI gauge to measure 5 -15 PSI pressure. Select instead a 0 - 30 PSI gauge.

### Gross Head vs. Net Head

By recording these actual measurements, you have determined *Gross Head*. As described later in *Computing Net Head*, however, the effective Head at the nozzle is actually lower when water begins to flow, due to pipeline (penstock) friction. A properly designed pipeline will yield a *Net Head* of about 85%-90% of the Gross Head you measured.

## Measuring Flow

Stream levels change through the seasons, so it is important to measure FLOW at various times of the year. If this is not possible, attempt to determine various annual flows by discussing the stream with a neighbor, or finding government geological survey flow data for your stream or a nearby larger stream. Also keep in mind that fish, birds, plants and other living things rely on your stream for survival. Especially during low water seasons, avoid using *all* the water for your hydro system.

FLOW is typically expressed as some volume of water per second or minute. Common examples are gallons or liters per second (or minute), and cubic feet or cubic meters per second (or minute): Each can be easily converted to another, as follows:

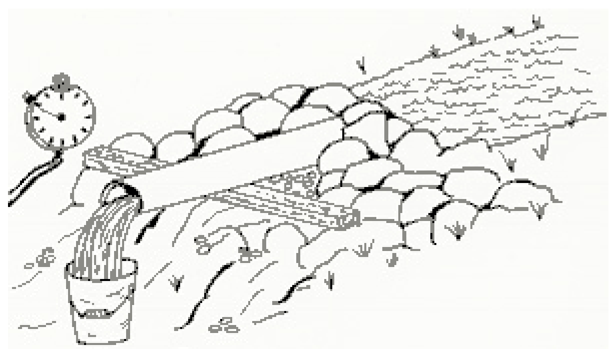
- 1 cubic foot = 7.481 gallons
- 1 cubic meter = 35.31 cubic feet
- 1 cubic meter = 1,000 liters

There are three popular methods for measuring FLOW: using a Container, Float, or Weir. Each will be described in detail below. Once again, accuracy is important to ensure correct system design and optimum power generation.

### *Method 1: Measuring Time to Fill Container*

The Container Fill method works only for very small systems.

Build a temporary dam that forces all the water to flow through a single outlet pipe, Using a bucket or larger container of a known volume, use a stopwatch to time how long it takes to fill the container. Then, divide the container size by the number of seconds.



Example:

Container = 5 gallon paint bucket

Time to fill = 8 seconds

- 5 gallons / 8 seconds = 0.625 gallons per second (gps)

To convert into Cubic Feet per Second (cfs):

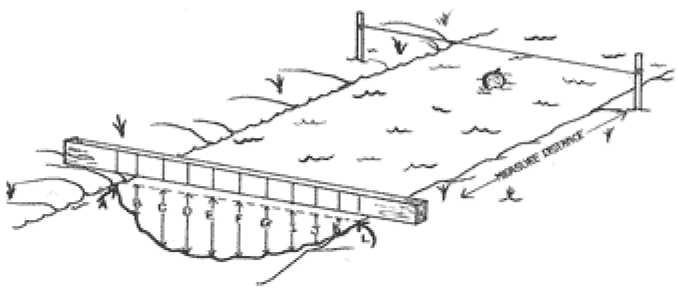
- 7.481 gallons per second = 1 cubic foot per second, so
- 0.625 gps / 7.481 = 0.0835 cubic feet per second (cfs).

### *Method 2: Measuring with a Float*

The Float method is useful for large streams if you can locate a section about 10 feet long where the stream is fairly consistent in width and depth.

**STEP 1: Measure the average depth of the stream.** Select a board able to span the width of the stream and mark it at one-foot intervals. Lay the board across the stream, and measure the stream depth at each one-foot interval. To compute the average depth, add all of your measurements together and divide by the number of measurements you made.



**STEP 2: Compute the area of the cross section you just measured.** Multiply the average depth you just computed by the width of the stream. For example, a 6-foot wide stream with an average depth of 1.5 feet would yield a cross section area of 9 square feet.

**STEP 3: Measure the Speed.** A good way to measure speed is to mark off about a 10-foot length of the stream that includes the point where you measured the cross section. Remember, you only want to know the speed of the water where you measured the cross section, so the shorter the length of stream you measure, the better.

Using a weighted float that can be clearly seen (an orange works well), place it in the stream well upstream of your measurement area, and then use a stopwatch to time how long it takes to cover the length of your measurement section (e.g. 10 feet). The stream speed probably varies across its width, so record the times for various locations and average them.

With these time and distance measurements, you can now compute the water speed.

For example, let's assume it took 5 seconds for your float to travel 10 feet:

- 10 feet / 5 seconds = 2 feet per second, or
- 2 feet per second x 60 = 120 feet per minute

You can then compute FLOW by multiplying the feet traveled by the cross section area. Using our cross section area and speed examples:

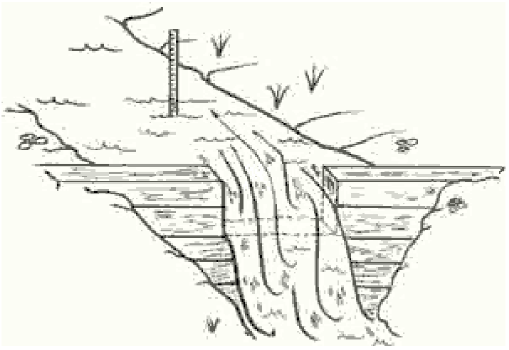
- 120 feet per minute x 9 square feet = 1,080 cubic feet per minute (cfm) FLOW

**STEP 4: Correct for Friction.** Because the stream bed creates friction against the moving water, the bottom of the stream tends to move a little slower than the top. This means actual flow is a little less than what we computed. By multiplying our result by 0.83, we get a closer approximation of actual flow:

- 1,080 CFM x 0.83 = 896.4 cfm (cubic feet per minute), or
- 896.4 CFM / 60 = 14.94 cfs (cubic feet per second)

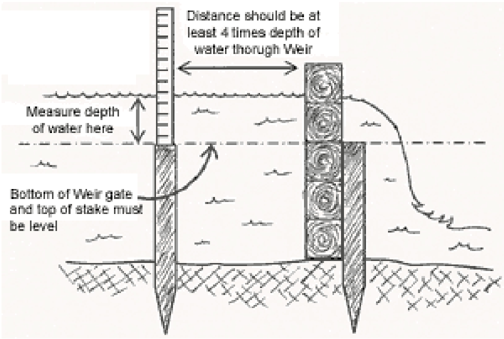
*Method 3: Measuring with a Weir*

A Weir is perhaps the most accurate way to measure small and medium sized streams. All the water is directed through an area that is exactly rectangular, making it very easy to measure the height and width of the water to compute FLOW.



A Weir is a temporary dam with a rectangular slot, or Gate. The bottom of the Gate should be exactly level, and the width of the Gate should allow all the water to pass through without spilling over the top of the dam. A narrower Gate will increase the depth of the water as it passes through, making it easier to measure.

It's important to note that your depth measurement is not taken at the gate itself because the water depth distorts as it moves through the gate. Instead, insert a stake well upstream of the Weir gate and make the top of the stake exactly level with the bottom of the Wier gate. Measure the depth of the water from the top of the stake.




Once the width and depth of the water are known, a Weir Table is used to compute the flow. The Weir Table shown below is based on a Gate one inch wide; you simply multiply the table amount by the width (in inches) of your Gate. For example, let's assume your Weir Gate is 6" wide, and the depth of the water passing over it is 7-1/2 inches. On the left side of the table, find "7" and move across the row until you find the column for "+1/2". The table shows 8.21 cfm flow for a one-inch Gate with 7-1/2" of water flowing through it. Since your gate is 6" wide, simply multiply the 8.21 by 6 to get 49.26 cfm.

| **Inches** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **+0/8** | **+1/8** | **+1/4** | **+3/8** | **+1/2** | **+5/8** | **+3/4** | **+7/8** |
| **0** | 0.00 | 0.01 | 0.05 | 0.09 | 0.14 | 0.19 | 0.26 | 0.32 |
| **1** | 0.40 | 0.47 | 0.55 | 0.64 | 0.73 | 0.82 | 0.92 | 1.02 |
| **2** | 1.13 | 1.23 | 1.35 | 1.46 | 1.58 | 1.70 | 1.82 | 1.95 |
| **3** | 2.07 | 2.21 | 2.34 | 2.48 | 2.61 | 2.76 | 2.90 | 3.05 |
| **4** | 3.20 | 3.35 | 3.50 | 3.66 | 3.81 | 3.97 | 4.14 | 4.30 |
| **5** | 4.47 | 4.64 | 4.81 | 4.98 | 5.15 | 5.33 | 5.51 | 5.69 |
| **6** | 5.87 | 6.06 | 6.25 | 6.44 | 6.62 | 6.82 | 7.01 | 7.21 |
| **7** | 7.40 | 7.60 | 7.80 | 8.01 | 8.21 | 8.42 | 8.63 | 8.83 |
| **8** | 9.05 | 9.26 | 9.47 | 9.69 | 9.91 | 10.13 | 10.35 | 10.57 |
| **9** | 10.80 | 11.02 | 11.25 | 11.48 | 11.71 | 11.94 | 12.17 | 12.41 |
| **10** | 12.64 | 12.88 | 13.12 | 13.36 | 13.6 | 13.85 | 14.09 | 14.34 |
| **11** | 14.59 | 14.84 | 15.09 | 15.34 | 15.59 | 15.85 | 16.11 | 16.36 |
| **12** | 16.62 | 16.88 | 17.15 | 17.41 | 17.67 | 17.94 | 18.21 | 18.47 |
| **13** | 18.74 | 19.01 | 19.29 | 19.56 | 19.84 | 20.11 | 20.39 | 20.67 |
| **14** | 20.95 | 21.23 | 21.51 | 21.80 | 22.08 | 22.37 | 22.65 | 22.94 |
| **15** | 23.23 | 23.52 | 23.82 | 24.11 | 24.40 | 24.70 | 25.00 | 25.30 |
| **16** | 25.60 | 25.90 | 26.20 | 26.50 | 26.80 | 27.11 | 27.42 | 27.72 |
| **17** | 28.03 | 28.34 | 28.65 | 28.97 | 29.28 | 29.59 | 29.91 | 30.22 |
| **18** | 30.54 | 30.86 | 31.18 | 31.50 | 31.82 | 32.15 | 32.47 | 32.80 |
| **19** | 33.12 | 33.45 | 33.78 | 34.11 | 34.44 | 34.77 | 35.10 | 35.44 |
| **20** | 35.77 | 36.11 | 36.45 | 36.78 | 37.12 | 37.46 | 37.80 | 38.15 |

A Weir is especially effective for measuring FLOW during different times of the year. Once the Weir is in place, it is easy to quickly measure the depth of the water and chart FLOW at various points in time.

### *Design Flow*

Even though your Flow may be very high after exceptionally rainy periods, it probably won't be cost effective to design your turbine system to handle all that water for just a few days of the year. Instead, it makes sense to build a system that uses Flow you can count on for much of the year. This is called *Design Flow*, and it is the maximum Flow your hydro system is designed to accommodate.

Design Flow, along with Net Head, determines everything about your hydro system, from pipeline size to power output.

# How the Penstock Affects Head Pressure

## Measuring Pipeline (Penstock) Length

The length of your pipeline (also known as the penstock) has a major influence on both the cost and efficiency of your system, as we'll discuss below. The measurement is easy, though. Simply run a tape measure between your intake and turbine locations, following the route you'll use for your pipeline.

## Computing Net Head

In the section *Measuring Head* you measured *Gross Head* – the true vertical distance from intake to turbine – and the resulting pressure at the bottom when no water is flowing. *Net Head*, on the other hand, is the pressure at the bottom of your pipeline when water is actually flowing to your turbine, and will always be less than the Gross Head you measured due to energy losses within the pipeline. Longer pipelines and smaller diameters create greater friction.

Net Head is a far more useful measurement than Gross Head and, along with Design Flow, is used to determine hydro system components and power output. This section will show you the basics for determining pipeline size and Net Head, but we suggest you work with your turbine supplier to finalize your pipeline specifications.

### *Head Loss*

Head Loss refers to the loss of water power due to friction within the pipeline (also known as the penstock). Although a given pipe diameter may be sufficient to carry all the Design Flow, the sides, joints and bends of the pipe create drag as the water passes by, slowing it down. The effect is the same as lowering the Head; there will be less water pressure at the turbine.

Note that the effects of Head Loss cannot be measured unless the water is flowing. A pressure meter at the bottom of even the smallest pipe will read full PSI when the water is static in the pipe. But as the water flows, the friction within the pipe reduces the velocity of the water coming out the bottom. Greater water flow increases friction further.

Larger pipes create less friction, delivering more power to the turbine. But larger pipelines are also more expensive, so there is invariably a tradeoff between Head Loss and system cost. A good rule of thumb is to size your pipe so that not more than 10% to 15% of the Gross (total) Head is lost as pipeline friction.

The following table provides an example of how to determine the appropriate pipe (penstock) size.

**Head Loss Chart**

| **Design Flow** | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GPM | .25 | .50 | 100 | 150 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1000 | 1200 |
| CFS | .05 | .1 | .2 | .33 | .45 | .66 | .89 | 1.1 | 1.3 | 1.5 | 1.78 | 2.0 | 2.23 | 2.67 |
| **Pipe size and loss per 100 feet** | | | | | | | | | | | | | | |
| 2” | 1.28 | 4.65 | 16.8 | 35.7 | 60.6 | 99.2 | | | | | | | | |
| 3” | .18 | .65 | 2.33 | 4.93 | 8.36 | 17.9 | 30.6 | 46.1 | 64.4 | | | | | |
| 4” | .04 | .16 | .57 | 1.23 | 2.02 | 4.37 | 7.52 | 11.3 | 15.8 | 21.1 | 26.8 | 33.4 | | |
| 6” | | .02 | .08 | .17 | .29 | .62 | 1.03 | 1.36 | 2.2 | 2.92 | 3.74 | 4.75 | 5.66 | 8.04 |
| 8” | | | | .04 | .07 | .15 | .25 | .39 | .5 | .72 | .89 | 1.16 | 1.4 | 1.96 |

Example Site Characteristics:

- Gross Head = 100 feet
- Pipeline length = 400 feet
- Acceptable Head Loss = 10% -15% (10-15 feet)
- Design Flow = 200 gallons per minute

To determine what size pipe would be best, look up your Design Flow (200 GPM) in the Head Loss Chart above. Our maximum acceptable Head Loss is 15 feet (15% of our 100-foot Gross Head), which means we cannot exceed 3.75 feet loss for every 100 feet of our 400-foot pipeline. Reading down the column under 200 GPM, we find that a four-inch pipe would cause a loss of 2.02 feet per 100 feet – within our limits.

Using a four-inch pipeline, Head Loss for this example would be:

- Head Loss = 2.02 feet (per 100 feet) x 4 = 8.08 feet

Therefore, Net Head for this example would be:

- Net Head = 100 feet – 8.08 feet = 91.92 feet

Note the significant difference in Head Loss between 3-inch and 4-inch pipes. Likewise, a 6” or 8” pipe would cause even less Head Loss and deliver more power to the turbine, but the performance improvement may not be sufficient to justify the added cost.

Keep in mind that these Head Loss computations assume a straight pipe; they do not take into account bends in your pipeline that can rob significant power from your water. Your turbine manufacturer should be well versed in measuring head losses, and can be an excellent resource for pipe diameter recommendations.

# Calculating the Power in Your Stream

## Computing Water Power

Once you've determined Net Head and Design Flow, you can begin to estimate the power output from your hydro system. *These computations are only rough estimates*; consult with your turbine supplier for more accurate projections.

We begin by computing the *theoretical* power output from your water, before taking into consideration any efficiency losses in the turbine, drive system, and generator.

You can compute the *Theoretical Power* of your water supply as either Horsepower or Kilowatts using one of these formulas:

$$\text{Theoretical Horsepower* (HP)} = \frac{\text{HEAD (feet) x FLOW (cfs)}}{8.8}$$

$$\text{Theoretical Kilowatts* (kW)} = \frac{\text{HEAD (feet) x FLOW (cfs)}}{11.81}$$

* Note that these are *Theoretical Power* equations, which do not account for the inevitable efficiency losses that will occur at various points within your hydro system. The actual power output of your generator will be less, as we'll discuss later.

**Hypothetical Example:**

A stream in New Zealand has 100 feet of HEAD, with 2 cubic feet per second (cfs) of FLOW. Applying our formula, we find that we should have about 17 theoretical kW available:

$$\text{kW} = \frac{\text{100 (feet) x 2 (cfs)}}{11.81} = \text{16.93 Theoretical Kilowatts*}$$

As you can see, both HEAD and FLOW have a linear effect on power. Double the head, and power doubles. Double the flow, and power doubles.

Also keep in mind that HEAD will remain constant once your system is installed; you can count on it year-round. It is also the least expensive way to increase power generation because it has minimal affect on turbine size. In contrast, FLOW will likely change over the course of a year, and it may not be cost-effective to size your hydro system for maximum, flood-level Flow. Always maximize Head, and work with your turbine supplier to determine the most practical Design Flow.

*Accuracy is important!* The design of your turbine revolves around your measurements of Head and Flow, and errors will directly impact the efficiency of your system. Take the time to measure Head and Flow accurately before you begin to evaluate hydro system components.

### Adjusting for Efficiency Losses

As noted earlier, the Theoretical Power calculations shown above represent a theoretical maximum, and the actual power output from your hydro system will be substantially less. In addition to the pipeline losses discussed earlier, small amounts of power will be lost through friction within the turbine, drive system, generator, and transmission lines.

Although some efficiency losses are inevitable, don't underestimate the importance of good design. Efficient systems produce greater power output, often at a lower cost-per-watt. For example, a turbine system that is carefully matched to your Head and Flow may not cost any more than a less suitable design, but produce much greater efficiency. Other improvements, such as larger pipeline diameter or a better drive system, may yield enough added power to justify their higher cost.

Because of the many variables in system design, it is impossible to estimate efficiency without first knowing your Head and Flow. As a general guideline, however, you can expect a home-sized system generating direct AC power to operate at about 60% - 70% "water-to-wire" efficiency (measured between turbine input and generator output). Larger utility systems offer much better efficiencies. Smaller DC systems generally have lower efficiencies.

If you have accurate measurements for your Head and Flow, your turbine supplier should be able to provide some preliminary estimates of efficiency, as well as ideas for optimization.

## Measuring Transmission Line Length

The last important measurement is the length of your transmission line between your generator and the point of electrical usage. As with your pipeline, you can simply measure the distance along the route you plan to run your wiring.

Transmission lines are a lot like pipelines. Instead of moving water, they move electrical current, but the same fundamentals of friction losses apply. Longer transmission lines, smaller wires, and higher current all contribute to power loss through friction. You can minimize these losses, but the power you can actually use will always be somewhat less than what your generator is producing.

Power loss over transmission lines is most evident by a drop in voltage. As you use more power, you'll see the voltage drop and lights glow dimmer.

There are three ways to reduce, or compensate for, transmission line losses:

1. Shorten the transmission line
2. Use a larger wire
3. Increase the voltage on the transmission line

Shorter lines and larger wires will reduce line losses for any system. For very long runs, it may be appropriate to boost the voltage (via a transformer) for transmission, and then reduce it back to normal (via another transformer) at the point of usage. Boosting the voltage reduces the current necessary to produce the same amount of power, allowing the use of smaller wires.

Your turbine supplier can help you determine the best approach.

# Part 3: Evaluating Turbine Systems and Suppliers

As we've shown, a hydro system is both simple and complex. The concepts behind water power are simple: it all comes down to Head and Flow. But good design requires advanced engineering skills, and reliable operation requires careful construction with quality components.

## What Makes a Quality Turbine System

Think of a turbine system in terms of efficiency and reliability. In a perfect world, efficiency would be 100%. All the energy within the water would be transformed to the rotating shaft. There would be no air or water turbulence, and no resistance from bearings. The runner would be perfectly balanced. The signs of energy loss – heat, vibration and noise – would be absent. Of course, the perfect turbine would also never break down or require maintenance.

*Quality components and careful machining make a big difference in turbine efficiency and reliability.*

Obviously no turbine system will ever achieve this degree of perfection. But it's good to keep these goals in mind, because better efficiency and reliability translate to more power and a lower cost-per-watt. Here are just a few of the things to consider when selecting a turbine system:

### Turbine Runner

The runner is the heart of the turbine. This is where water power is transformed into the rotational force that drives the generator. Regardless of the runner type, its buckets or blades are responsible for capturing the most possible energy from the water. The curvature of each surface, front and rear, determines how the water will push its way around until it falls away. Also keep in mind that any given runner will perform most efficiently at a specific Head and Flow. The runner should be closely matched to your site characteristics.

Look for all-metal runners with smooth, polished surfaces to eliminate water and air turbulence. One-piece, carefully machined runners typically run more efficiently and reliably than those that are bolted together. Bronze manganese runners work well for small systems with clean water and Heads up to about 500 feet. High-tensile stainless steel runners are excellent for larger systems or abrasive water conditions. All runners should be carefully balanced to minimize vibration, a problem that not only affects efficiency but can also cause damage over time.

### Turbine Housing

The turbine housing must be well built and sturdy, as it manages forces of the incoming water as well as the outgoing shaft power. In addition, its shape and dimensions have a significant affect on efficiency. For example, consider a Pelton-type turbine. As an impulse turbine, it is driven by one or more jets of water, but spins in air. This means that both hydrodynamic and aerodynamic forces must be considered in the design of the housing. It must minimize the resistance from splash and spray and smoothly exhaust tail waters, yet also be sized and shaped properly to minimize losses due to air turbulence. Similarly, housings for high-Flow designs like Crossflow and Francis turbines must be precisely engineered to smoothly channel large volumes of water through the turbine without causing pockets of turbulence.

Look for a smoothly welded housing that is carefully matched to the proper runner for your site. Keep in mind that both the water forces and the runner will be producing considerable torque, so the housing material and all fittings should be heavy-duty. Mating surfaces, such as pipe flanges and access covers, should be machined flat and leak-free. Since water promotes rust and corrosion, make sure all vulnerable surfaces are protected with high quality powder coat or epoxy paint. All bolts should be stainless steel.

## Other Turbine Considerations

All surfaces that carry water can impact efficiency, from the intake to your pipeline to the raceway that carries the tail waters away from your powerhouse. Look for smooth surfaces with no sharp bends, Jets and flow control vanes should be finely machined with no discernable ripples or pits.

Efficiency is important, but so are durability and dependability. Your hydroelectric project should deliver clean power without interruption. The quality of components – and their installation – can make a big difference on the quality of your life in the years to come.

Look for meticulous workmanship in the design and construction of seal systems, shaft material and machining, and all related components. Pay particular attention to the selection and mounting of bearings; they should spin smoothly, without grating or binding.

## Turbine Supplier

When it comes to suppliers, there is no substitute for experience. While the principles of hydro power can be mastered indoors, it is real world experience that teaches both the highlights and pitfalls of diverting water from a stream, pressurizing it, and forcing it through a turbine. A turbine supplier with many years of field experience will be invaluable to you as your design and build your hydro system.

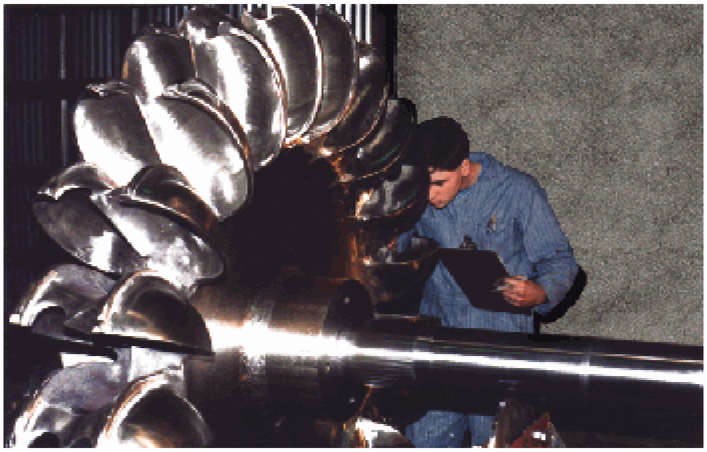
Look for an experienced supplier that specializes in the size and type of hydro system you intend to build. A good supplier will work with you, beginning with your measurements of Head and Flow, to help you determine the right pipeline size, Net Head, Design Flow, turbine specifications, drive system, generator, and load management system. You should be able to count on your supplier to make suggestions for optimizing efficiency and dependability, including their effects on cost vs. performance.

A good turbine supplier is your partner, and should take a personal interest in your success. After all, a satisfied customer is very good for business.

# Closing Thoughts

We hope you have found this *Guide to Hydro Power* helpful. We admit we've only scratched the surface of this substantial topic, but we're happy to discuss your hydro project in detail when appropriate.

As you've seen, the concepts behind hydro power are simple. Water turns a turbine, the turbine spins a generator, and electricity comes out the other side. Even a novice with little or no experience could produce some hydroelectricity – given enough water power



*All Canyon Hydro turbines are carefully inspected before shipping.*

But we've also emphasized efficiency and durability – getting the most power for your hard-earned money. Unless you have much more water than you need, you'll want to squeeze every possible watt out of your stream. You will also want a rock-solid system that continues delivering reliable power year after year. Not surprisingly, the systems we build at Canyon Hydro live up to the standards we emphasize throughout this *Guide*.

We have to admit, we love hydro. We take great satisfaction in finding new ways to make hydro-electric generation easier and more practical. For more than 35 years, we've continually improved our turbine designs and system components. Canyon Hydro systems are remarkably efficient and highly reliable; the systems we installed 35 years ago are still running today. Perhaps that's why Canyon Hydro systems, from 5Kw to 10Mw and beyond, are producing reliable electrical power all over the world.

Thank you for taking the time to read through our *Guide to Hydro Power*. If we can be of help with your hydro project, please contact us.

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If you have comments or suggestions about the content of this *Guide to Hydro Power*, please let us know at feedback@canyonhydro.com.