Measuring the stream course—Anna and Joe work downstream, shooting vertical drop (head) with a sight level, and getting a rough measurement of the pipe run at the same time.

Small-scale hydro is the only renewable energy source that works for you 24 hours a day, 7 days a week. In the first article in this series (*HP103*), I explained the basics of hydroelectric system theory, and reviewed system components. This article focuses on measuring a stream's head and flow. Before you can begin designing your hydro system or estimating how much electricity it will produce, you'll need to make four essential measurements:

- Head (the vertical distance between the intake and turbine)
- Flow (how much water comes down the stream)
- Pipeline (penstock) length
- Electrical transmission line length (from turbine to home or battery bank)

This article will discuss how to measure head and flow. Head and flow are the two most important facts you need to know about your hydro site. You simply cannot move forward without these measurements. Your site's head and flow will determine everything about your hydro system—pipeline size, turbine type, rotational speed, and generator size. Even rough cost estimates will be impossible until you've measured head and flow.

When measuring head and flow, keep in mind that accuracy is important. Inaccurate measurements can result in a hydro system designed to the wrong specs, and one that produces less electricity at a greater expense.

A handheld sight level, or peashooter, is a handy and inexpensive tool for determining the head of your hydro site.

Measuring Head

Head is water 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 higher output—at the turbine.

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 (46 m) or more, even when calibrated. GPS altimeters are often even less accurate. Topographic maps can also be used to give you a very rough idea of the vertical drop along a section of a stream's course. But only two methods of head measurement are accurate enough for hydro system design—direct height measurement and water pressure.

Direct Height Measurement

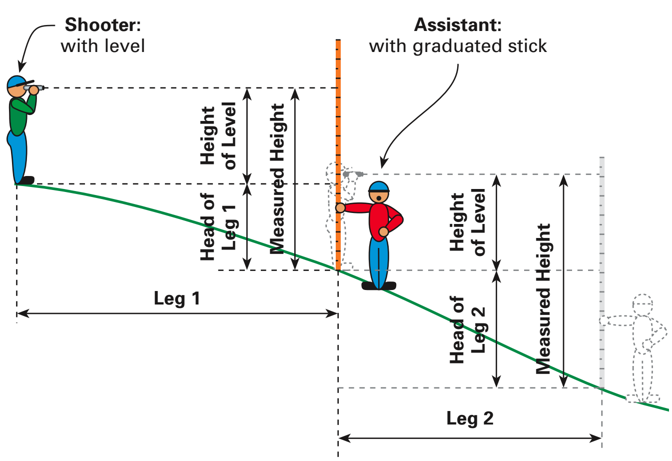
To measure head, you can use a laser level, a surveyor's transit, a contractor's level on a tripod, or a sight level ("peashooter"). Direct measurement requires an assistant.

One method is to work downhill using a tall pole with graduated measurements. A measuring tape affixed to a 20-foot (6 m) section of PVC pipe works well. After each measurement, move the transit, or person with the sight level, to where the pole was, and begin again by moving the pole further downhill toward the generator site. Keep each transit or sight level setup exactly level, and make sure that the measuring pole is vertical. Take detailed notes of each measurement and the height of the level. Then, add up the series of measurements and subtract all of the level heights to find total head.

View through the sight level—Anna measured 7 feet 4 inches on the leveling rod. By subtracting the height of her eye, she determined the head for this section to be 1 foot 8 inches.

Another method is to work uphill, with your assistant walking up the slope as you site through the transit or sight level until the bottoms of the assistant's feet are level with the transit. At this point, the head will be the same as the distance from your eye to the ground where you are standing. Once you've recorded this measurement, move to the spot where your assistant was standing, and repeat the process. Multiply the number of times you do this by the height of the shooter's eye from the ground for the total head.

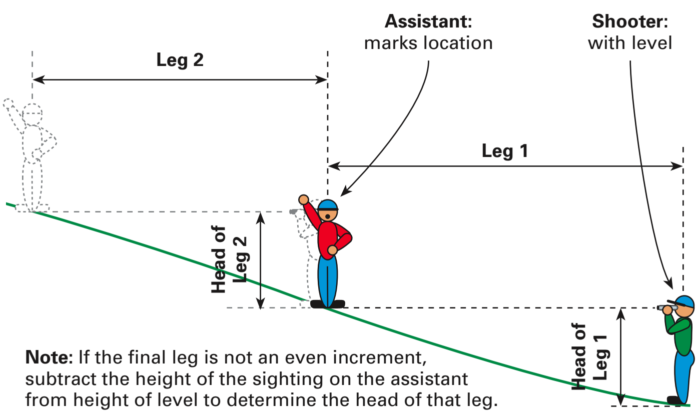
Measuring Downhill



1. **Subtract height of level from measurment on stick to determine head for each leg.**
2. **Repeat multiple legs from intake location to turbine location.**
3. **Add the head of each leg together to determine total head.**

Measuring Uphill

1. **Height of level is head for each leg.**
2. **Repeat multiple legs from turbine location to intake location.**
3. **Multiply the height of level times the number of legs to determine total head.**



Note: If the final leg is not an even increment, subtract the height of the sighting on the assistant from height of level to determine the head of that leg.

Courtesy of Liquid Sun Hydro

A pressure gauge connected to a hose can provide accurate head measurements. Convert pressure to height, or purchase a gauge like the one above and read height directly.

Water Pressure Measurement

If the distance is short enough, you can use one or more garden hoses or lengths of flexible plastic tubing 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 creates 4.33 psi). By measuring the pressure at the bottom of the hose, you can calculate the elevation change.

Run the hose (or tubing) from your proposed intake site to your proposed turbine location. If you attach multiple hoses together, make sure that each connection is tight and leak free. Attach an accurate pressure gauge to the bottom end of the hose, and completely fill the hose with water. Make sure that there are no high spots in the hose that could trap air. You can flush water through the hose before the gauge is connected to force out any air bubbles.

If necessary, you can measure total head over longer distances by moving the hose and taking multiple readings. Keep in mind, however, that there is less than $^1/_2$ psi difference for every vertical foot. Except for very steep hillsides, even a 100-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 gauge.

The pressure gauge must be graduated so that measurements are taken in the middle of its range. Don't use a 0 to 800 psi gauge to measure 5 to 15 psi pressure. Select instead a 0 to 30 psi gauge. Liquid Sun Hydro now sells pressure gauges calibrated in feet, which makes head measurement a snap.

Computing Net Head

By recording the measurements described in the previous sections, you have determined gross head—the true vertical distance from intake to turbine, and the resulting pressure at the bottom. Net head, on the other hand, is the pressure at the bottom of your pipeline when water is actually flowing to your turbine. This will always be less than the gross head you measured, due to friction losses within the pipeline. You will need to have water flow figures (described in the following sections) to compute net head. Longer pipelines, smaller diameters, and higher flows create greater friction. A properly designed pipeline will yield a net head of 85 to 90 percent of the gross head you measured.

Net head is a far more useful measurement than gross head and, along with design flow, is used to determine hydro system components and electrical output. Here are the basics of determining pipe size and net head, but you should work with your turbine supplier to finalize your pipeline specifications.

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 of 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—less water pressure at the turbine.

Head loss cannot be measured unless the water is flowing. A pressure gauge 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 flows increase 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 trade-off between head loss and system cost. Size your pipe so that not more than 10 to 15

Head Loss in PVC Pipe*

	Design Flow in Gallons per Minute & (Cubic Feet per Second)													
Pipe Size (in.)	**25 (.05)**	**50 (0.1)**	**100 (0.2)**	**150 (0.33)**	**200 (0.45)**	**300 (0.66)**	**400 (0.89)**	**500 (1.1)**	**600 (1.3)**	**700 (1.5)**	**800 (1.78)**	**900 (2.0)**	**1,000 (2.23)**	**1,200 (2.67)**
2	1.28	4.65	16.80	35.70	60.60	99.20	-	-	-	-	-	-	-	-
3	0.18	0.65	2.33	4.93	8.36	17.90	30.60	46.10	64.40	-	-	-	-	-
4	0.04	0.16	0.57	1.23	2.02	4.37	7.52	11.30	15.80	21.10	26.80	33.40	-	-
6	-	0.02	0.08	0.17	0.29	0.62	1.03	1.36	2.20	2.92	3.74	4.75	5.66	8.04
8	-	-	-	0.04	0.07	0.15	0.25	0.39	0.50	0.72	0.89	1.16	1.40	1.96

*In feet per 100 feet of pipeline

percent of the gross (total) head is lost as pipeline friction. Higher losses may be acceptable for high-head sites (100 feet plus), but pipeline friction losses should be minimized for most low-head sites.

The length of your pipeline has a major influence on both the cost and efficiency of your system. 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. Remember that you want to run the pipeline up out of the creek bed, when possible, to avoid damage during high water.

Anna gets her feet wet—the container fill method of measuring flow means getting in the stream and timing how long it takes to fill a container of known volume.

Measuring Flow

The second major step in evaluating your site's hydro potential is measuring the flow of the stream. 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 U.S. 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. Never use all of the stream's water for your hydro system.

Flow is typically expressed as volume 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

Three popular methods are used for measuring flow—container, float, and weir. Each will be described in detail below.

Container Fill Method

The container fill method is the most common method for determining flow in microhydro systems. Find a location along the stream where all the water can be caught in a bucket. If such a spot doesn't exist, build a temporary dam that forces all of the water to flow through a single outlet. 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.

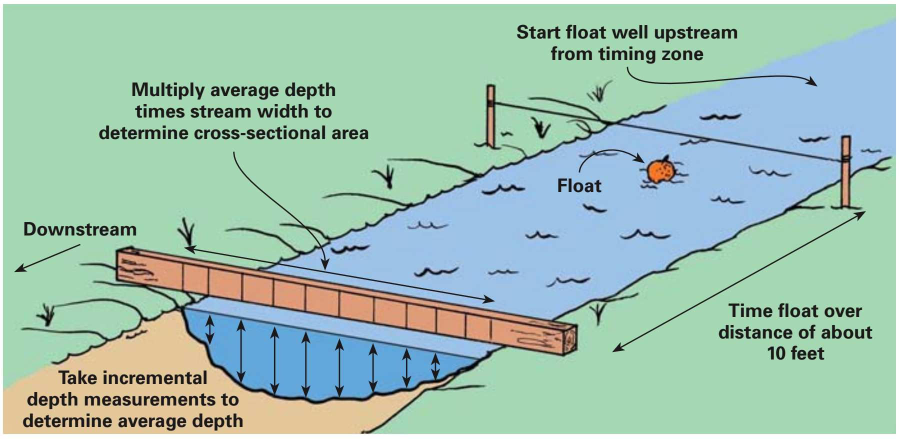
For example, if your container is a 5-gallon paint bucket and it takes 8 seconds to fill, your flow is 0.625 gallons per second (gps) or 37.5 gallons per minute (gpm).

Float Method

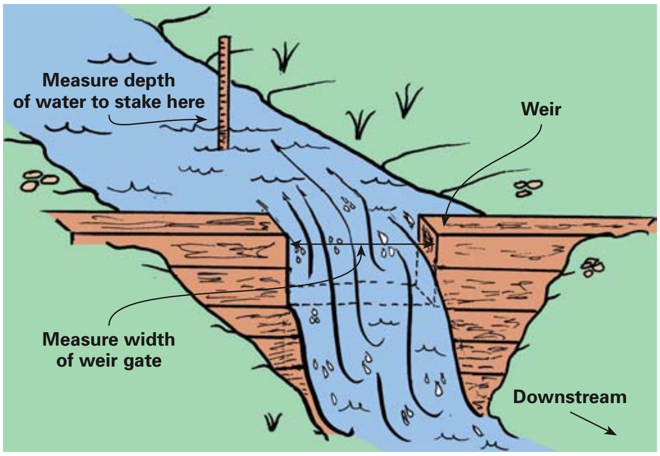
The float method is useful for large streams if you can locate a section about 10 feet (3 m) long where the stream is fairly consistent in width and depth.

Step 1. Measure the average depth of the stream. Select a board able to span the width of the stream and mark it at 1-foot (0.3 m) intervals. Lay the board across the stream, and measure the stream depth at each 1-foot interval. To compute the average depth, add all of your measurements together and divide by the number of measurements you made.

The Float Method of Estimating Flow



The Weir Method of Measuring Flow

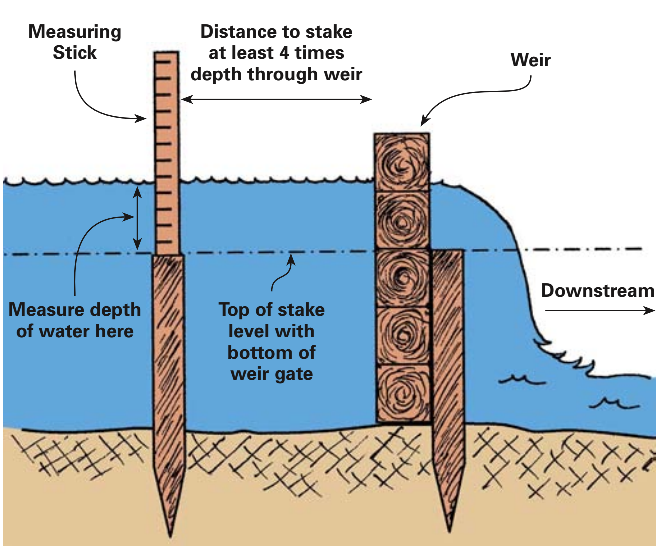


Step 2. Compute the area of the cross-section you just measured by multiplying the average depth you just computed by the width of the stream. For example, a 6-foot-wide stream with an average depth of 1.5 feet would yield a cross-sectional area of 9 square feet.

Step 3. Measure the speed. A good way to measure speed is to mark off a 10-foot (3 m) 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.

Use a weighted float that can be clearly seen—an orange or grapefruit works well. Place it well upstream of your measurement area, and use a stopwatch to time how long it takes to travel the length of your measurement section. The stream speed probably varies across its width, so record the times for various locations and average them.

The Weir Method (continued)



With these time and distance measurements, you can now compute the water speed. For example, assume the float took an average of 5 seconds to travel 10 feet. That's 2 feet per second, or 120 feet per minute. You can then compute flow by multiplying the feet traveled by the cross-sectional area. Using the sample cross-sectional area and speed examples, 120 feet per minute times 9 square feet equals 1,080 cubic feet per minute (cfm) flow.

Step 4. Correct for friction. Because the streambed 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 was calculated. By multiplying the result by a friction factor of 0.83, you get a closer approximation of actual flow.

Weir Method

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.

This kind of 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.

Weir Flow Table*

Depth (in.)	Additional Fraction of an Inch							
	None	+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	13.60	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

*In cfm per 1-inch gate width

Example Site Analysis

Gross head: 100 feet

Pipeline length: 500 feet

Acceptable head loss: 10 to 15 percent (10–15 feet)

Design flow: 100 gpm

To determine what size pipe would be best, look up your design flow (100 gpm) in the head loss chart on page 44. In this example, the maximum acceptable head loss is 10 to 15 feet, which means we cannot exceed 3 feet of loss for every 100 feet of our 500-foot pipeline. Reading down the 100-gpm column, we find that a 3-inch pipeline would have a head loss of 2.33 feet per 100 feet of pipe—within our limits.

To determine total head loss, multiply 2.33 feet times 5 (for 500-foot pipeline), which equals 11.65 feet. To calculate net head, subtract the total head loss from the gross head (100 feet minus 11.65 feet). This gives us a net head of 88.35 feet.

Note the huge difference in head loss as pipe diameter gets smaller. Using a 2-inch pipeline, head loss for this example would be 16.8 feet per 100 feet, with a total head loss of 84 feet. Net head for this example would be 100 feet minus 84 feet, and result in only 16 feet of net head! This example shows how incorrectly sized pipelines can absolutely cripple a hydro system.

Choosing a 4-inch pipe would result in less head loss than 3-inch pipe, and deliver more power to the turbine, but the performance improvement is not sufficient to justify the added cost. Your turbine manufacturer should be well versed in measuring head losses, and can be an excellent resource for pipe diameter recommendations.

The 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 weir 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 here is based on a gate that is 1 inch (25 mm) wide. Simply multiply the table amount by the width (in inches) of your gate. For example, assume your weir gate is 6 inches wide, and the depth of the water passing over it is $7\frac{1}{2}$ inches. On the left side of the table, find "7" and move across the row until you find the column for "+$\frac{1}{2}$". The table shows 8.21 cfm flow for a 1-inch gate with $7\frac{1}{2}$ inches of water flowing through it. Since your gate is 6 inches wide, simply multiply the 8.21 by 6 to get 49.26 cfm.

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 the flow at various times.

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.

Next Steps

Determining the potential of your water resource is the first step for a well-designed and viable hydropower system. As you can see, measuring head and flow are not difficult or complex tasks. With your net head and design flow, you have enough information to begin the next step—talking with turbine suppliers about potential designs. But there are still a few more issues to consider. Next time, I'll discuss losses, efficiency, transmission, and predicting the electrical output of your system. Once you have that information, you'll be ready to install your hydropower system.

Access

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