Project Objectives:

1. Provide an overview of micro hydroelectric energy theory, systems, and components.
2. Demonstrated understanding of stream mapping, including estimation of head and flow for small micro hydro sites.
3. Demonstrated ability to determine penstock materials, including type, length, diameter, and placement.
4. Demonstrated ability to determine appropriate micro hydro turbines and appropriate turbine sites.
5. Demonstrated understanding of electricity generation, transmission, and storage from micro hydro sites.
6. Demonstrated ability to work in the field with peers to create a coherent documentation of project accomplishments.

Student Tasks:

1. Measure stream attributes to determine power output.
2. Create a stream profile.
3. Select appropriate microturbine, penstock, and electrical components for a micro hydroelectric site.
4. Prepare a report to summarize findings and outline potential improvements.
5. Give an oral presentation of their micro hydro system.

Selected References:

1. Boyle, G. 2004. Renewable Energy: Power for a sustainable future. 2nd Ed. Oxford University Press. 452 p.
2. **Davis, S. 2003. Microhydro: clean power from clean water. New Society Publishers. Canada. 176 p.**
3. Kemp, W.H. 2005. The Renewable Energy Handbook. Chapter 8. Aztext Press. Canada. 567 p.
4. Ostermeier, J. and J. Schwartz. The electric side of hydropower. Home Power 126: 68-73.
5. Schaeffer, J. 2008. Solar Living Sourcebook. Chapter 3. New Society publishers. Canada. 634 p.

<u>Project Overview</u>:

Hydroelectric power generation comes in two broad categories: large-scale hydro sites (generally those exceeding 5-30 MW, though this is a loose boundary) and small-scale hydro. Small-scale hydro is further broken down by a subset of very small systems, termed “micro hydro” (microhydro) on sites producing less than 30 kW of continuous power (again, this is a loose definition).

Whether large- or small-scale, hydroelectric power generation is dependent upon incoming solar radiation for movement of water throughout the hydrological cycle. As

precipitation from the atmosphere lands on uneven terrestrial environments, surficial flow that is channeled in streams and rivers is pulled to a lower elevation by gravitational forces. Where flow (volume of water) and head (elevation drop) are of adequate size and location, humans can extract a portion of the kinetic energy in moving water and convert it into electrical energy for consumption in useful electrical loads such as lights, refrigerators, and automatic pencil sharpeners.

Though the sustainability of large-scale hydroelectric plants has been increasingly questioned through time (primarily because of habitat degradation for aquatic organisms, structural instability, and high maintenance costs), micro hydroelectric power generation is considered one of the most useful and under-utilized renewable energy systems available for grid-tied and off-grid home applications. The remainder of this project will guide you through the process of measuring a stream, designing an appropriate microhydro system to harvest its energy, and designing the appropriate electrical components of a complete microhydro system.

Morrisville State College has two potential sites for microhydro installations: the Galbreath Stream and the Electric Light Stream. The one will be visiting is located just south of the Galbreath Farm off of North Street. This is a small stream with interesting land use history that will pose unique challenges in designing a working microhydro system.

Have fun and good luck!

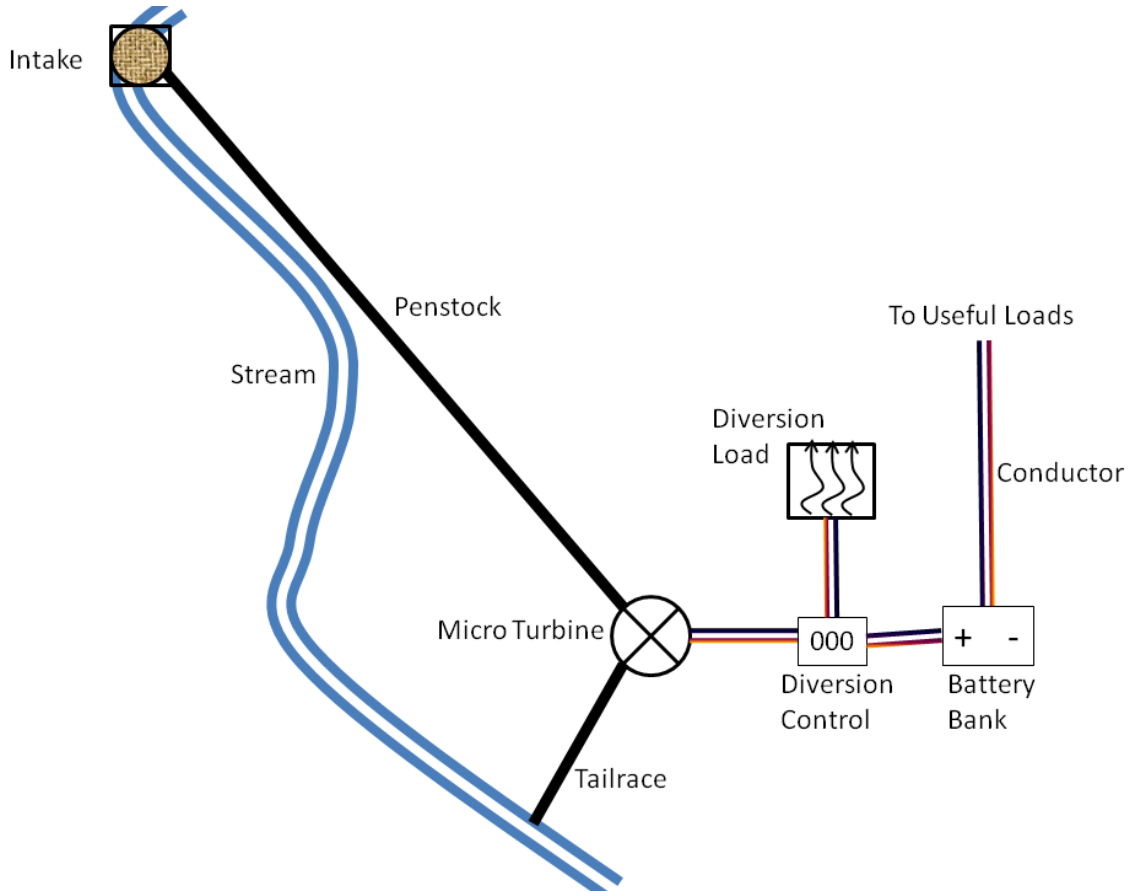

Figure 1. Overview diagram of a DC microhydro system.

The primary components of a microhydro system necessary to generate electricity include an intake, penstock pipe, and the turbine. To transmit electricity, a microhydro system must have (at minimum) a conductor, battery bank, diversion control, diversion load, and a useful energy load. Each of these will be described in further detail below.

Measuring a stream

Our first exercise as a class is to measure the flow and head of the stream. **Flow** is the quantity of water moving past a given point over a set time period (expressed as volume in gallons per minute (gpm) or cubic meters per second (m^3/s). **Head** is the vertical distance that water descends in altitude as a result of gravity. Head is measured either in feet (or meters) or with units of pressure (pounds per square inch (psi) or kilopascals (kPa)). It is useful to note that **2.31 feet of head is equal to 1 psi**. For example, a stream with 200 feet of head will have approximately 87 psi at the turbine nozzle (200 feet ÷ 2.31 feet/psi = 86.6 psi). Most streams have inverse relationships between head and flow; they tend to be either high head with low flow or low head with

high flow. In situations where there is high head and high flow, one is likely to find a large-scale hydroelectric plant. Streams with low flow and low head are generally not suited to electric power generation.

There are many methods to measure stream head. The most accurate methods include use of a transit or total station in combination with a range pole. If sophisticated surveying equipment is not available, a sight level and distance measuring tape can achieve the same goal (Figure 2). If rough estimates are needed, a GPS or watch altimeter may also be used. **Beware:** inaccuracies in head measurement become more critical as total head measured decreases!

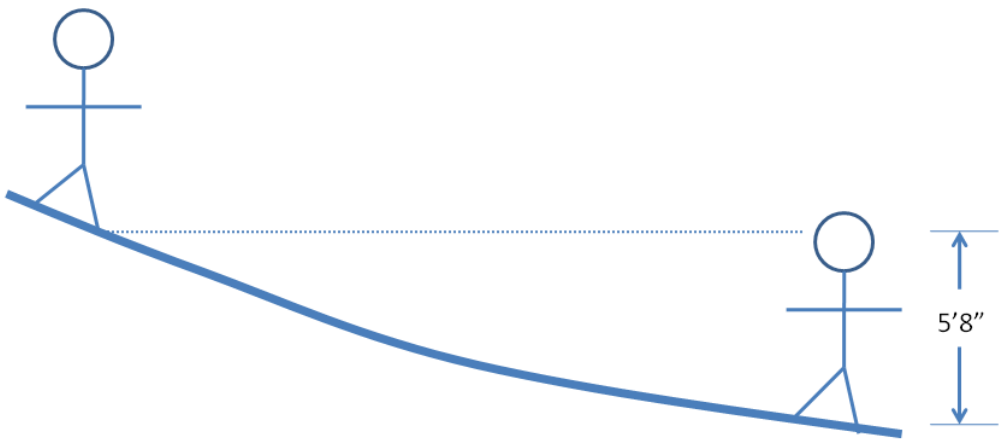

Figure 2. A 2-person team measuring stream head with a sight level. **Note**: elevation difference is NOT the total body height of the person shooting the level line; it is the height from the ground to the observer's eyes.

Stream flow can also be measured with several methods. In low flow streams, one can simply collect the flowing water in a container of known volume for a measured period of time (Figure 3). In streams with a higher flow, flow can be measured by constructing a weir of known dimensions and measuring the time necessary for the pooled water to rise to a known height. For yet higher flows, depth to the stream bottom can be measured along successive points transverse to stream flow at upstream and downstream locations a known distance apart. A floating object (like an orange or grapefruit) can be placed at the upstream line and timed to float to the downstream line. This will allow for calculations of water volume and water movement (multiplied by a friction coefficient for rocky stream bottoms). **Beware**: Inaccuracies in measurement of flow become more critical as flow levels decline!

In addition to measuring the head and flow of a stream, it is also useful to create a **stream profile** of the section you are investigating as a potential hydro site (Figure 4). Take care to note particularly steep and shallow sections, areas where running penstock will be difficult, and other hazards. It is also helpful to note penstock angle changes where necessary.

Figure 3. Students measuring flow in a small high-head, low-flow stream by determining the time necessary to fill a 5-gallon bucket.

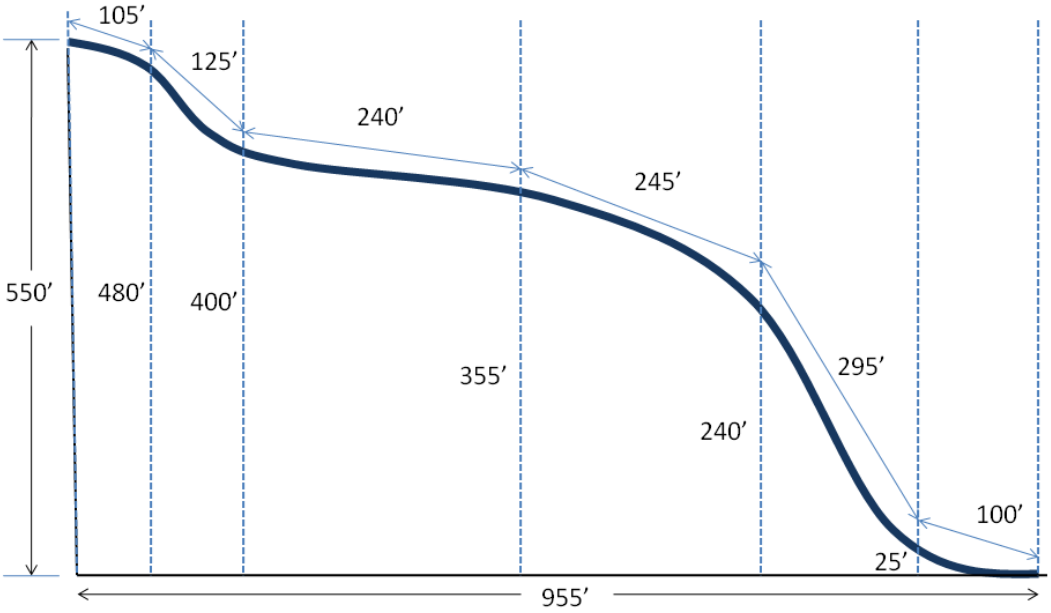

Figure 4. A simplified stream profile diagram. Cumulative head is on the y-axis, penstock length for each section is noted following the stream contour. For this example, total head is 550' or 238 psi (550 ft ÷ 2.31 ft per psi). Total penstock length is 1,110'.

Selecting the proper penstock

Once stream head and flow have been accurately ascertained, one can select the proper penstock material and size and find the proper micro turbine. **Penstock** is the pipeline that brings water from the screened collection point to the turbine nozzles. It is imperative to select the proper diameter, length and material for your system penstock. All penstock restricts flow within the piping due to friction; in general, larger diameter penstock will have lower losses.

Most microhydro systems are designed with an upper stop valve and a pressure relief near the intake to avoid creating a vacuum in the penstock, a drain valve just upstream of the turbine, a pressure gauge below the drain valve to measure penstock water pressure, and a lower stop valve between the pressure gauge and the turbine (Figure 5). When the lower stop valve is closed, water will stop flowing through the penstock to the systems maximum static head height (increasing the system pressure to 1 psi per 2.31 vertical ft). As the valve is opened and water begins to flow, the observed pressure will drop (head loss) due to friction losses in the penstock pipe. **Note:** the vacuum relief pipe must exceed the water intake elevation.

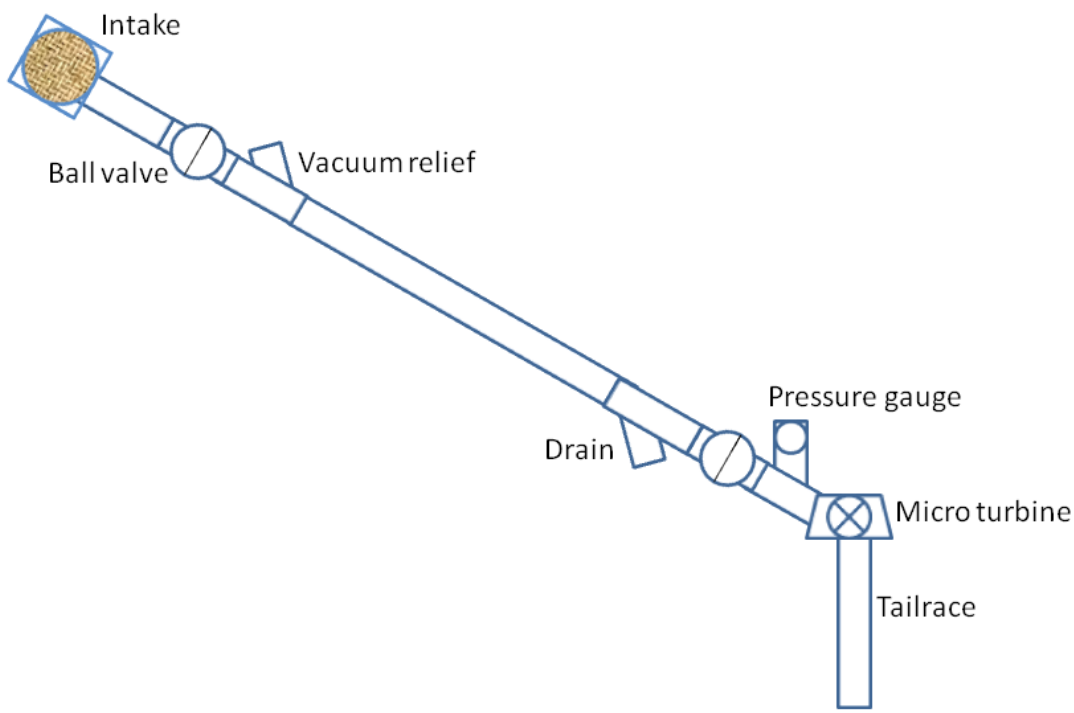

Figure 5a. Penstock components diagram (the bare necessities!).


Figure 5b. Upstream vacuum relief and ball valve (left) and downstream drain, pressure gauge, and ball valve that will be located just upstream of the micro turbine (right).

There are two commonly used penstock materials: polyvinyl chloride (PVC) and polyethylene. The pipe flow chart below (Table 1) indicates that for a given flow and head, PVC penstock will result in lower head loss (opened stop valve) for a given diameter pipe. It must also be noted that PVC is a rigid pipe product in specific lengths that must be glued, while polyethylene is flexible and comes in a continuous coil. Cost of penstock pipe can vary greatly depending upon material chosen, length of run, and desired diameter. Also bear in mind the necessary fittings, couplings, valves, and bends necessary for each type of penstock material when making decisions.

It is also worth noting that idealized friction losses (based on material and diameter alone) do not necessarily take into account the number of acute bends in any given penstock layout. PVC realized head losses are frequently larger than the idealized losses stated below as the number of acute bend fittings increase. For this reason, actual head losses in polyethylene penstock systems may be lower than PVC losses for a given penstock run.

Table 1. Friction loss rates for Polyethylene and PCV penstock pipe (after Kemp 2005).

Polyethylene SDR Pipe Friction Losses (feet of head per 100 feet of pipe)						
	Pipe Diameter (inches)					
Flow (GPM)	0.50	0.75	1.00	1.25	1.50	2.00
1.00	1.13	0.28	0.09	0.02	-	-
2.00	4.05	1.04	0.32	0.09	0.04	-
3.00	8.60	2.19	0.67	0.19	0.09	0.02
4.00	14.60	3.73	1.15	0.30	0.14	0.05
5.00	22.10	5.61	1.75	0.46	0.21	0.07
6.00	31.00	7.89	2.44	0.65	0.30	0.09
7.00	41.20	10.50	3.24	0.85	0.42	0.12
8.00	53.10	13.40	4.14	1.08	0.51	0.16

9.00		16.70	5.15	1.36	0.65	0.18
10.00		20.30	6.28	1.66	0.78	0.23
12.00		28.50	8.79	2.32	1.11	0.32
14.00		37.90	11.70	3.10	1.45	0.44
16.00			15.00	3.93	1.87	0.55
18.00			18.60	4.90	2.32	0.69
20.00			22.60	5.96	2.81	0.83

Class 160 PVC Pipe Friction Losses (feet of head per 100 feet of pipe)

1.00	0.05	0.02	-	-	-	-
2.00	0.14	0.05	0.02	-	-	-
3.00	0.32	0.09	0.04	-	-	-
4.00	0.53	0.16	0.09	0.02	-	-
5.00	0.80	0.25	0.12	0.04	-	-
6.00	1.13	0.35	0.18	0.07	0.02	-
7.00	1.52	0.46	0.23	0.08	0.02	-
8.00	1.93	0.58	0.30	0.10	0.04	-
9.00	2.42	0.71	0.37	0.12	0.05	-
10.00	2.92	0.87	0.46	0.16	0.07	0.02
11.00	3.50	1.04	0.53	0.18	0.07	0.02
12.00	4.09	1.22	0.64	0.20	0.09	0.02
14.00	5.45	1.63	0.85	0.28	0.12	0.04
16.00	7.00	2.09	1.08	0.37	0.14	0.04
18.00	8.69	2.60	1.33	0.46	0.18	0.07
20.00	10.60	3.15	1.63	0.55	0.21	0.07

Selecting the proper turbine

Power, the number of joules per second (watts) of kinetic energy in the water resource, is equally a function of head and flow. The power supplied is the rate at which energy is delivered and can be described with the equation:

$$P(W)=QH/10$$

where P is the power in watts, Q is the quantity of water or rate of flow (gpm), and H is the effective head (ft). **Effective head** is the static head minus the losses incurred by the friction of flowing water in your chosen penstock pipe. Therefore, if we had a stream with a flow rate of 16 gpm a measured head of 124 feet and an effective head of 120 feet, we would expect our power output to be 192 continuous watts (16 gpm*120 feet ÷ 10).

One advantage that a properly sized micro hydro systems have over other renewable energy systems is that continuous power is produced 24 hours a day, 365 days per year. Both solar and wind energy systems have power output fluctuations throughout

the day and throughout the year (Figure 6). Therefore, estimating energy output per day/week/month is quite straightforward for hydro systems. For the example given in the previous paragraph, daily energy output in kWh is found as:

192 watts x 1 hour x 24 hours/day = 4608 watt-hours/day = 4.6 kWh/day

Our monthly energy output expected, therefore, is 138 kWh/month (4.6 kWh/day * 30 days/month). Keep this figure in mind once system costs come into the discussion. Micro hydro systems can be quite cost-effective!

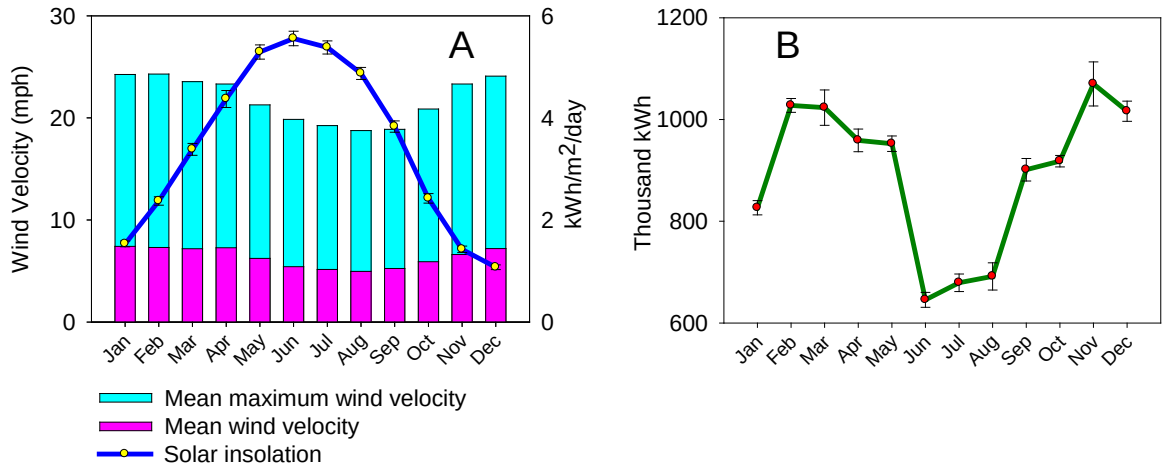

Figure 6. Monthly comparison of solar and wind resources (A) at the Morrisville State College campus in central New York in reference to mean monthly electricity needs (B).

Once power estimates have been made, one can select the appropriate turbine for the site. In general, there are two types of turbines to choose from (though there are more, and hybrids are common): impulse turbines and reaction turbines. **Impulse turbines** are most common for high head, low flow sites, while **reaction turbines** are most common with low head, high flow sites.

The two most common types of impulse turbines are the Turgo and the Pelton. In the **Turgo**, a jet of water from the nozzle strikes the turbine runners at an angle. Significant power can be generated with relatively little head. Like the Turgo, **Pelton** turbines are particularly suited to low flow, high head sites. Water jets from the nozzle strike along the circumference of the turbine blades.

Nozzle selection is also important in microhydro systems. Nozzle size is limited by the size of the turbine runners (blades), flow rates, and penstock diameter. Many turbines on today's market are capable of utilizing more than one nozzle (Figure 7). In these situations, it is common to use nozzles with differing diameters that can be turned on or off depending upon the time of year and the flow rates. Nozzle diameter greatly impacts the jet flow rate of the system and should be matched with the stream flow rates (Table 2).

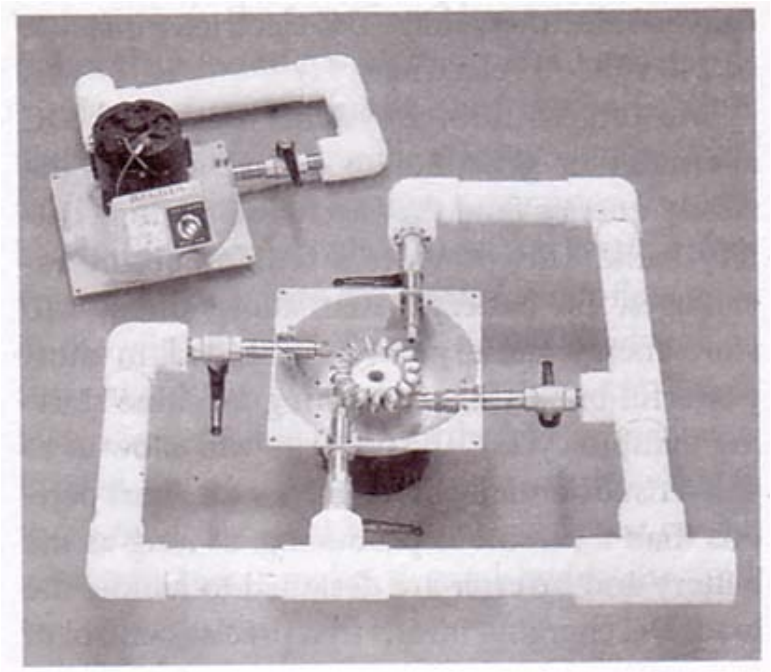

Figure 7. Pelton style turbine with 4 nozzles (from Schaeffer 2008).

Table 2. Jet flow rates (gallons per minute) for nozzle diameters at a given penstock PSI.

Net PSI	Nozzle diameter (inches)									
	0.1250	0.1875	0.2500	0.3750	0.4375	0.5000	0.5625	0.7500	0.8750	1.0000
2	-	-	-	6.2	8.4	11.0	14.0	24.7	33.0	43.7
4	-	-	6.1	8.8	11.6	15.8	19.5	35.0	47.6	61.6
7	-	-	7.4	10.7	14.6	10.6	24.0	42.8	58.2	75.7
10	-	3.3	5.9	13.3	18.1	23.6	30.2	53.1	72.5	94.5
20	2.1	4.7	8.4	18.8	25.6	33.4	42.4	75.1	102	134
25	2.3	5.3	9.3	21.0	28.7	37.3	47.3	84.0	115	149
30	2.6	5.8	10.2	23.0	31.4	40.9	51.9	92.0	126	164
35	2.8	6.2	11.1	24.8	33.8	44.2	56.1	99.5	136	177
40	3.0	6.6	11.8	26.6	36.2	47.3	59.9	106	145	189
50	3.3	7.4	13.2	29.7	40.5	52.8	67.0	119	162	21
60	3.6	8.1	14.5	32.5	44.3	57.8	73.3	130	177	231
75	4.1	9.1	16.2	36.4	51.2	64.7	84.4	146	205	259
100	4.7	10.5	18.7	42.1	57.3	74.7	95.0	168	229	299

DC micro hydro systems

Many micro hydroelectric systems are used to charge batteries. Because microhydro is not intermittent like many other renewable energy systems, batteries can be charged at a constant rate, 24 hours a day. Because of this, even small micro hydro systems can produce a significant amount of stored electrical energy relative to other alternative energy systems. Additionally, micro hydro battery banks tend to be smaller because of frequent recharging.

In all renewable energy systems, during periods of little energy use (low discharge), batteries become fully charged. To avoid overcharging batteries, excess energy must be sent to a **diversion load** (aka dump load). A diversion control routes energy from the fully charged battery bank to a load that is good at "wasting" energy (e.g. air heaters or water heaters). Diversion loads for DC micro hydro systems should be high current, low output devices because of the low system voltage.

True DC systems are useful for small cabins or when daily energy requirements are particularly low. One can purchase components for an RV that require only DC (such as light bulbs, refrigerators, fans, and other useful loads). Most homes, however, require 120/240 VAC for a bulk of the electricity needs.

AC systems

Though DC is most commonly used for small microhydro applications, alternating current (AC) systems are most common in larger systems. Alternating current energy is simpler and more efficient than generating DC. DC renewable energy systems require conversion of AC to DC through a **rectifier** to charge batteries, and another conversion of DC to AC through an **inverter** for most electrical loads. Each conversion results in reduced useable energy (remember efficiency and the second law of thermodynamics!). Because most energy loads in a house require electricity in sine wave AC form, restricting the **alternator** to a constant rpm speed with a **governor** produces useable current without the need for charging batteries.

It must be made clear than many users *want* to charge batteries, however. A battery bank provides some backup in the case of no power generation (e.g. pipe freezes in the winter) and can store energy for larger peak loads (you start a refrigerator, microwave, and toaster at the same time). Using AC directly from the turbine must be sized appropriately for the end use needs, particularly in smaller microhydro installations.

Complex system designs making use of alternators, rectifiers, inverters, and charge controllers are beyond the scope of this particular project, but their importance in hybrid renewable energy systems should not be minimized.

Batteries

It is common for micro hydro systems to use "off-the-shelf" batteries for their energy storage. Micro hydro systems should always use **deep-cycle, lead-acid** batteries. These will deliver relatively constant voltage as the stored energy in the battery is

discharged. Additionally, deep-cycle batteries can be charged with lower amperage than standard "starting" batteries, such as those used in automobiles. Deep-cycle batteries can be discharged repeatedly down to 20% of their capacity (and recharged to full capacity) many times without degradation. Of the batteries available for microhydro systems, golf cart batteries are the most commonly used. They are inexpensive true deep-cycle batteries, are compact, and long lasting. It is recommended, however, that deep-cycle batteries designed specifically for off-grid homes be used when power to the home is critical (houses not grid-tied).

Unless stream flow rates are quite high (gallons per second vs. gallons per minute), residential applications of microhydro use low voltage DC to charge a battery bank. Battery banks for these systems produce between 12 to 120 VDC. Ideal turbine voltage is dependent upon the distance between the batteries and turbine. Also remember that this current needs to be inverted (converted to AC) for most home applications.

For turbine locations within a few hundred feet of the electrical load, wire routing costs will be relatively low. Longer runs require larger diameter **conductors** (copper wiring components). Recall the basic electricity power equation:

Volts x Amps = Watts

where volts and amps have an inverse relationship for a given wattage. In other words, high voltage results in lower amperage for a given wattage. The higher the amperage, the more energy is lost in transmission (inefficiency). High voltage transmissions will keep wire costs down because smaller diameter wires are needed for transmitting at lower amperage. Balancing transmission distances is a large decision in properly locating a microhydro system, as is selecting a turbine with the proper voltage output. To avoid damage to conductors, most are run in a **conduit** covering and buried.

Once the conductors are at the house, they are connected to a breaker system to control amperage surges. Microhydro systems can be connected to additional hybrid renewable energy components such as wind and solar in battery banks.

Please see further course project outlines for a deeper discussion of wire sizing, charge controllers, inverters, and battery bank sizing. **Each of these components is critically important to designing an energy system that meets safety codes.**

Your group will need to address the following aspects of the Galbreath Farm microhydro site:

1. Standing head (both feet and psi)
2. Stream flow rate
3. Total pipeline distance
4. Penstock material
5. Penstock diameter
6. Friction loss in penstock (head loss per 100 feet and total head loss)
7. Effective head (feet and psi)
8. Turbine selection (specific model, make, volts)
9. Expected continuous power output of the system (watts)
10. Expected monthly energy output of the system (kWh)
11. Size of the battery bank (voltage, Ah, number of batteries, specific model)
12. Potential uses of the electricity
13. System costs (Penstock pipe and fittings, turbine, and battery bank)

This project will need to be in technical document form, written as if your group were a consulting firm for a prospective client interested in microhydroelectric power generation. You will need to include a full site assessment, including but not necessarily limited to: maps identifying the site location, stream profile diagrams, system components and costs, potential pitfalls of the site, positive attributes of the site, and any additional information that you feel a potential buyer would need to have. Like any professional document, you will be assessed on the document's technical content as well as its grammar, spelling, punctuation, and the like.

We will be constructing this system on **Thursday, October 30th** so you must have each of the 12 components listed above outlined (values determined, with mathematic work shown) by the beginning of class on **Thursday, October 23rd**. Final reports are due at the beginning of class on **Thursday, December 4th**. Your group will give the class a 15 minute presentation on your system components and on the modifications you would make to the system that was installed on October 30th. As stated in the syllabus, this project will be worth 25% of your total course grade. This will be broken down as:

System components (specification/design) -	25 points
Oral presentation -	25 points
Prepared document -	35 points
Group participation -	15 points
	100 points

Once again, good luck and have fun!