Asa Hurst, Jonathan Shimazu, Kate Fabian
Energy Systems, Winter Quarter 2008
Research Project Write-up

Assessing the Feasibility of Pico Hydroelectric Technology on TESC

Abstract: As a research team our hope was to assess the hydroelectric potential of the streams on The Evergreen State College. We hoped to utilize these resources to encourage knowledge and awareness about renewable energy. Over the course of eight weeks, our group collected data on volumetric flow from a site near Driftwood road, on the north side of campus. From this data we concluded that the observed energy of the steam ranged from enough to power a fluorescent light bulb during low flow to a high-end computer during heavier days. We determined that there was low potential for hydroelectric generation at the existing site; however this potential might be increased with structural modifications. The inconsistencies of volumetric flow, across seasons, create a barrier in the installation of a hydroelectric system. Undeterred, we've concluded that while the site requires further ecological analysis, it may be a suitable location for the development of hydroelectric systems. Its potential for electrical production may be minuscule, but the capacity for education is great.

Introduction: The Pacific Northwest is blessed with ample water, which creates great potential for small-scale hydroelectric power generation. Hydroelectric power, while not always considered 'green energy," since hydroelectric systems often have a major impact on their surroundings, can have very little environmental impact when practiced on a small scale. Furthermore, hydroelectricity is not subject to many of the challenges associated with solar and wind technology. It is already a proven technology, is not as finicky as wind power, and tends to do well in conditions where solar power suffers. For those reasons, we conducted an investigation to evaluate the theoretical maximum electricity that can be generated from a stream on The Evergreen State College campus. We wished to determine if micro hydro power could be a practical addition to Evergreen's energy portfolio.

Questions/Hypotheses:

Q1: Is the potential for hydroelectric energy generation great enough to offset the cost of installation and maintenance of a hydroelectric system?

> **Preferred Hypothesis**: The stream on the northern side of campus, along Driftwood road, is the location to which many of the campus drains lead. As rain runoff is a renewable resource, the greatest barrier to implementing hydroelectric technology is the initial capital investment. A hydroelectric installation is a viable endeavor as it requires little maintenance after its construction and the energy source is free.

Additionally, we predict a volumetric flow in streams around Evergreen Campus sufficient for the purpose of generating electricity. The location of the hydroelectric site is important.Proximity to infrastructure like roads and electricity lines will minimize the cost of construction and maintenance of a hydroelectric system. We prefer locations close to the main campus.

Alternative: Hydroelectric technology is infeasible on TESC at this time because the potential for generation fails to cover the expense of maintenance and/or micro hydro will not be competitive with conventional energy.

Null: There is no potential for electrical generation on/around TESC.

Q2: How will seasonal variations in rain fall effect the capacity of electrical generation?

Preferred Hypothesis: Winter rains would correspond with peak energy consumption, thus seasonal variations in rainfall would mostly follow a similar trend to demand for hydro electric generation in the Pacific Northwest. Because there is a tendency for heavier rainfall during the winter months, hydroelectric energy is more viable in the wetter seasons. However, during the summer months, in which there is less abundant rainfall, the opposite is true. This makes hydroelectric energy competitive with solar technology during winter months, when solar intensity is diminished.

It is unknown whether the stream will continue to flow in the summer. One prediction is that the forest around evergreen campus will be able to sustain some moisture during the summer months. This may help regulate flow rates in streams during the dry season.[4]

Alternative: Variations in rainfall would not drastically influence energy production because the amount of flow that hydro systems could utilize would remain under levels of variation or fluctuations in flow would be indiscernible.

Null: There are no seasonal variations in rain fall.

Q3: What will be the environmental, social, and economic impacts of implementing a micro hydro system?

Preferred Hypothesis: The local negative impacts of a micro hydro system would be minimal given the small scale of the operation. If no water is diverted there will be no associated disturbances. One area of concern is that excessive disturbances to the forest ecosystem will occur during visitations to each site. These events can be minimized by exercising caution. While the environmental results of implementing a micro hydro system will be localized it is predicted that the social results will have a greater positive impact.

In conducting this investigation, it is hoped that others will be inspired to implement other systems utilizing alternative energies. The combined effort of many individuals will develop a local capacity to construct and maintain hydroelectric installations.

Economically, it is unlikely that installing a small hydroelectric system will have profound effects. The extra energy may help Evergreen attain some energy independence, but in comparison to the energy the College consumes, it is probably negligible.

We hope to develop a site for students to learn about hydro electricity, and possibly to inspire them to apply hydroelectric systems for their own uses in the future. We also wish to spread knowledge of hydroelectricity to others on campus.

Alternative: In utilizing the mechanical energy of flowing water on evergreen campus, the ecological balance that many aquatic organisms are sensitive to may be disrupted. while a run-of-the-river system may have a lower impact on the local ecosystem, this is a greater concern if micro hydro developments were to be implemented in more places. If the impacts are widespread enough, it could result in public outrage.

Null: The environment is not affected by small scale micro hydro developments. Furthermore, this project is insignificant and will not receive much attention.

Methods:

Locating Potential Streams –

A preliminary investigation was conducted to determine a suitable location for a micro hydro construction site. Three locations around TESC were evaluated based on water flow stability, site accessibility, and energy potential. These sites were narrowed down to one which was continuously monitored for the remainder of the quarter. [1]

We decided on a point of the stream located nearest to Driftwood road which we named the Culvert. The site consists of a small dam and reservoir which features a metal barrier behind the dam that catches floating debris and a metal catwalk which covers the entire structure. Water emerges from a large subterranean pipe and a smaller PVC drainage pipe at the back of the reservoir. Since a dam already exists, construction of a hydroelectric system would have reduced ecological consequences. The site is already constructed and has a small road to it, so the hydroelectric system would be more accessible for construction and maintenance due to its proximity to existing infrastructure and the main campus. [2]

Two additional sites, which we designated the names “Yellow Tape” and “Asa’s Hole,” were considered for measurement and construction. Yellow Tape was a section of the stream which was focused into a steep and narrow channel and Asa’s Hole was a small waterfall which formed when a natural log dam collapsed and went under the log.

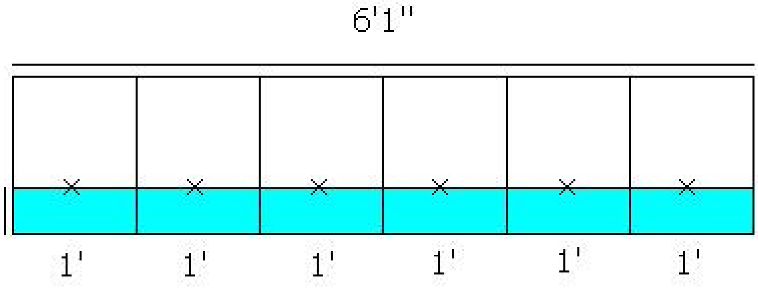
Both sites were rejected for a hydroelectric installation for concern over ecological sensitivity. At Yellow Tape we were concerned that a turbine there would be engulfed by the surrounding hills or would increase erosion of clay deposits along the banks of the stream. Furthermore, the distance from established paths meant both sites would have reduced accessibility, and a diminished educational value. This also would mean higher installation and maintenance difficulties.

Evaluating Stream Flow to Determine Potential Power Output–

Materials

1. **Current Meters**
2. **Stop Watch**
3. **Tape Measurer**

Power generated in a hydro installation is directly proportional to the mass of water flowing through the turbine. In order to estimate the potential energy of a stream, we must know the volume of water flowing through it.



To find volumetric flow, the cross section of the stream was split into 6 approximately one foot-wide sections. The depth and current was then measured in about the middle of each section. We found that one measurement of the depth was good for all sections because the top of the dam was level and flat. The total cross sectional area of the stream could be found by summing the product of each sections width and depth. We then took two readings in the center of each section using the current meters. As the current meters are submerged into the stream, the water spins a propeller. We used the number of rotations of the propeller during a one minute time period to determine the streams velocity using the following formula provided in the current meter manual: (8.54*10^-4)C+0.05, C being the count displayed by the meter, the result being expressed in meters per second. We then multiplied the area of the steam by the stream's velocity to obtain the rate of volume flowing over the dam.

Determining Head

Head is the vertical height between where the water enters the hydroelectric system and where it exits the system, having transferred most of its energy. We measured from the top of the existing dam to the pool below it using a tape measurer. This is the accessible head if a run-of-of-the-river turbine was installed. The existing dam has a head of 0.4 meters but we think the surrounding concrete structure could be modified to accommodate a larger dam of up to a meter.

Determining Theoretical Power

Kinetic power was obtained using the kinetic energy formula $KE=\frac{1}{2}mv^2$, where we used the mass per second rate over the dam instead of just mass so that the formula would give power instead of energy. The average velocity of the stream is v. The velocity of each section of the stream was averaged together to get an average velocity. The mass is obtained by multiplying the volumetric flow of the steam by the density of water (1000 kg/m^3).

Gravitational power was obtained using the formula PE = mgh, where m is the mass, g is the gravitational constant 9.8 m/s^2, and h is the head. We modified the formula by putting mass flow per second in place of just mass, so the formula would give power instead of energy.

Example 1, Kinetic Power

$P_k = \frac{1}{2}\ (\text{mass/second})\ (\text{velocity})^2$

$P_k = \frac{1}{2}\ (\text{volume/second})\ (\text{density})\ (\text{velocity})^2$

$P_k = \frac{1}{2}\ (0.12\ m^3/s)\ (1000\ kg/m3)\ (0.89 m/s)^2$

$P_k = \frac{1}{2}\ (120\ kg/s)\ (0.89 m/s)^2$

$P_k = \frac{1}{2}\ (120\ kg/s)\ (0.79 m^2/s^2)$

$P_k = (60\ kg/s)\ (0.79 m^2/s^2)$

$P_k = 47.4\ kg\ m^2 / s^3$

$P_k = 47.4\ W$

Example 2, Gravitational Potential Power

$P_g = (\text{mass/second})\ (\text{gravitational constant})\ (\text{head})$

$P_g = (\text{volume/second})\ (\text{density})\ (9.8\ m/s^2)\ (.4\ m)$

$P_g = (0.12\ m^3/s)\ (1000 kg/m^3)\ (9.8\ m/s^2)\ (.4\ m)$

$P_g = (120\ kg/s)\ (9.8\ m/s^2)\ (.4\ m)$

$P_g = (120\ kg/s)\ (3.92\ m^2/s^2)$

$P_g = (120\ kg/s)\ (3.92\ m^2/s^2)$

$P_g = (120\ kg/s)\ (3.92\ m^2/s^2)$

$P_g = 470.4\ kg\ m^2 / s^3$

$P_k = 470.4\ W$

Data from Table *4*

Results

Table 1

Site Name: The Culvert					**Date**	1/18/2008
Stream Width in meters (English Units)	1.854	(6'1")				
Section Width in meters (English Units)	0.3048	(12")				
Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.025	0.0077	587	0.55	0.53	0.0041
		0.0077	541	0.51		
2)	0.025	0.0077	636	0.59	0.58	0.0045
		0.0077	608	0.57		
3)	0.025	0.0077	703	0.65	0.62	0.0048
		0.0077	624	0.58		
4)	0.025	0.0077	595	0.56	0.57	0.0044
		0.0077	632	0.59		
5)	0.025	0.0077	589	0.55	0.55	0.0043
		0.0077	591	0.55		
6)	0.025	0.0077	576	0.54	0.56	0.0043
		0.0077	607	0.57		
Total Flow Rate(m^3/s)	0.026	**Total Mass Flow (kg/s)**	26		**Average Total Velocity (m/s)**	0.57
Kinetic Power (W)	4.3					
Gravitational Potential Power (W) with h =.4 m	104				**Gravitational Potential Power (W) with h =.8**	207

Table 2

Site Name: The Culvert					**Date**	1/25/2008
Stream Width in meters (English Units)	1.854	(6'1")				
Section Width in meters (English Units)	0.3048	(12")				
Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.013	0.004	421	0.41	0.39	0.0015
			377	0.37		
2)	0.013	0.004	456	0.44	0.43	0.0017
			445	0.43		
3)	0.013	0.004	461	0.44	0.47	0.0018
			530	0.50		
4)	0.013	0.004	501	0.48	0.49	0.0019
			531	0.50		
5)	0.013	0.004	450	0.43	0.44	0.0017
			473	0.45		
6)	0.013	0.004	450	0.43	0.43	0.0016
			430	0.42		
Total Flow Rate(m^3/s)	0.010	**Total Mass Flow (kg/s)**	10		**Average Total Velocity (m/s)**	0.44
Kinetic Power (W)	1.0					
Gravitational Potential Power (W) with h =.4 m	40				**Gravitational Potential Power (W) with h =.8**	81

Table 3

Site Name: The Culvert	**Date** 2/1/2008
Stream Width in meters (English Units)	1.854 (6'1")
Section Width in meters (English Units)	0.3048 (12")

Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.051	0.015	773	0.71	0.71	0.011
	0.051	0.015	779	0.72		
2)	0.051	0.015	794	0.73	0.76	0.012
	0.051	0.015	866	0.79		
3)	0.051	0.015	860	0.78	0.79	0.012
	0.051	0.015	866	0.79		
4)	0.051	0.015	818	0.75	0.76	0.012
	0.051	0.015	844	0.77		
5)	0.051	0.015	823	0.75	0.76	0.012
	0.051	0.015	838	0.77		
6)	0.051	0.015	790	0.72	0.74	0.012
	0.051	0.015	836	0.76		

Total Flow Rate(m^3/s)	0.07	**Total Mass Flow (kg/s)**	70	**Average Total Velocity (m/s)**	0.75
Kinetic Power (W)	20				
Gravitational Potential Power (W) with h =.4 m	274			**Gravitational Potential Power (W) with h =.8**	549

Table 4

Site Name: The Culvert	**Date** 2/8/2008
Stream Width	1.854 (6'1")

in meters (English Units)		
Section Width in meters (English Units)	0.3048	(12")

Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.076	0.023	985	0.89	0.91	0.021
	0.076	0.023	1027	0.93		
2)	0.076	0.023	988	0.89	0.90	0.021
	0.076	0.023	1010	0.91		
3)	0.076	0.023	933	0.85	0.88	0.020
	0.076	0.023	1004	0.91		
4)	0.076	0.023	1045	0.94	0.93	0.022
	0.076	0.023	1027	0.93		
5)	0.076	0.023	887	0.81	0.84	0.019
	0.076	0.023	957	0.87		
6)	0.076	0.023	946	0.86	0.86	0.020
	0.076	0.023	946	0.86		

Total Flow Rate(m^3/s)	0.124	**Total Mass Flow (kg/s)**	124	**Average Total Velocity (m/s)**	0.89
Kinetic Power (W)	49				
Gravitational Potential Power (W) with h =.4 m	484			**Gravitational Potential Power (W) with h =.8**	969

Table 5

Site Name: The Culvert	**Date** 2/15/2008

Stream Width in meters (English Units)	1.854	(6'1")				
Section Width in meters (English Units)	0.3048	(12")				
Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.0254	0.0077	539	0.51	0.53	0.0041
			574	0.54		
2)	0.0254	0.0077	558	0.53	0.53	0.0041
			563	0.53		
3)	0.0254	0.0077	592	0.56	0.52	0.0040
			512	0.49		
4)	0.0254	0.0077	558	0.53	0.54	0.0042
			581	0.55		
5)	0.0254	0.0077	552	0.52	0.52	0.0040
			554	0.52		
6)	0.0254	0.0077	529	0.50	0.50	0.0039
			533	0.51		
Total Flow Rate(m^3/s)	0.024	**Total Mass Flow (kg/s)**	24		**Average Total Velocity (m/s)**	0.52
Kinetic Power (W)	3					
Gravitational Potential Power (W) with h =.4 m	95				**Gravitational Potential Power (W) with h =.8**	190

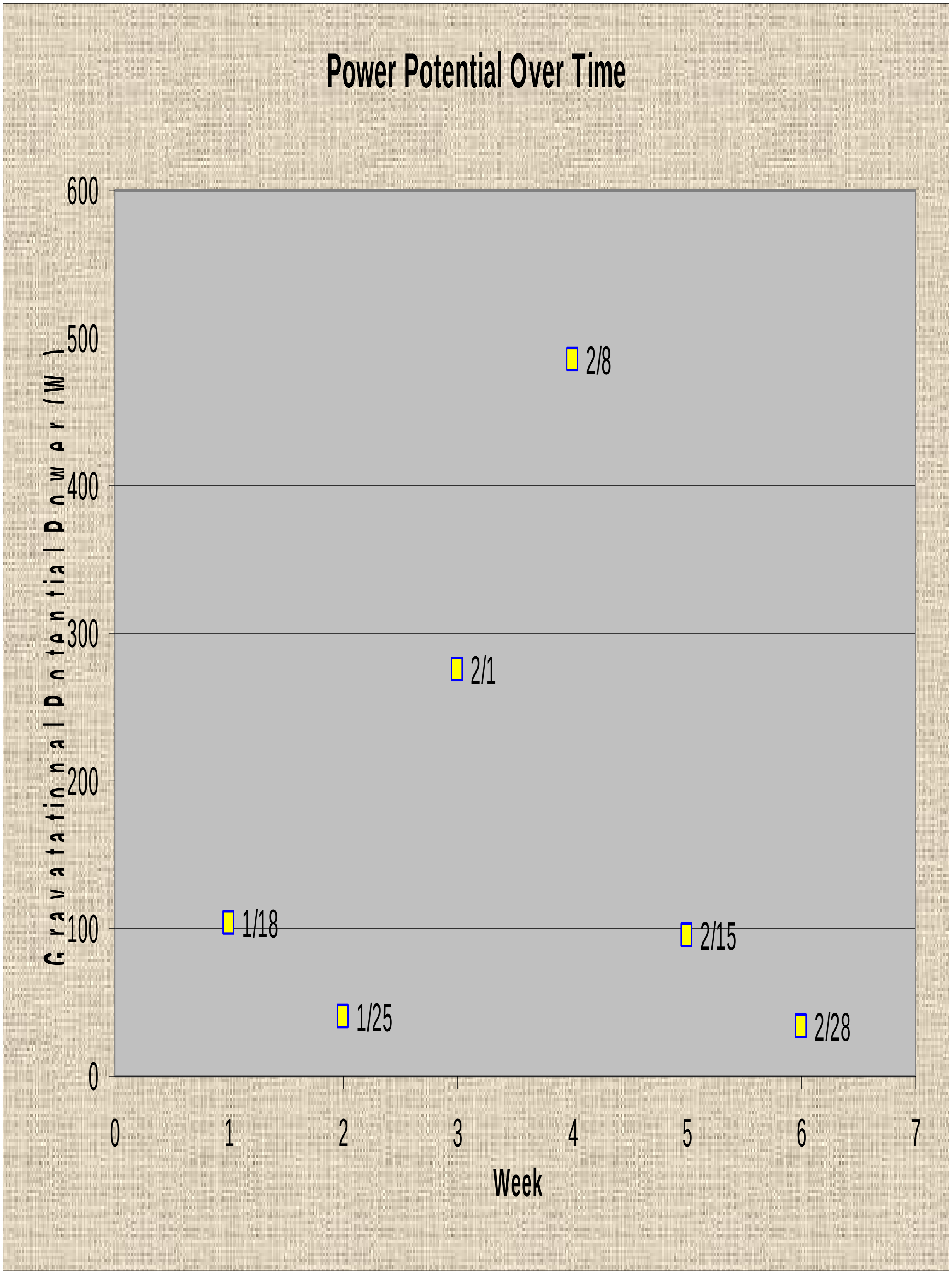
Table 6

Site Name: The Culvert	**Date** 2/28/2008

Stream Width in meters (English Units)	1.854	(6'1")
Section Width in meters (English Units)	0.3048	(12")

Observations: Section Mid Point	**Section Depth (m)**	**Area (m^2)**	**Counts Per Min**	**Velocity (m/s)**	**Average Velocity per section (m/s)**	**Section Flow Rate (m^3/s)**
1)	0.013	0.004	376 369	0.37 0.37	0.37	0.0014
2)	0.013	0.004	425 444	0.41 0.43	0.42	0.0016
3)	0.013	0.004	430 421	0.42 0.41	0.41	0.0016
4)	0.013	0.004	365 376	0.36 0.37	0.37	0.0014
5)	0.013	0.004	377 366	0.37 0.36	0.37	0.0014
6)	0.013	0.004	290 260	0.30 0.27	0.28	0.0011

Total Flow Rate(m^3/s)	0.0086	**Total Mass Flow (kg/s)**	8.6	**Average Total Velocity (m/s)**	0.37
Kinetic Power (W)	0.6				
Gravitational Potential Power (W) with h =.4 m	34			**Gravitational Potential Power (W) with h =.8**	67


Power Potential Over Time
Gravatational Potential Power (W)
600
500
400
300
200
100
0
0
1
2
3
4
5
6
7
Week
1/18
1/25
2/1
2/8
2/15
2/28

Considerations

According to the data collected during winter quarter the stream contained between 34 to 485 watts over a period of eight weeks (Table 1-6). Based on this amount we have concluded that a hydro electric installation at the Culvert would not produce significant power, at least in comparison to the amount current consumed by the college. This does not imply that it would not be economically beneficial, but it would not be a significant contribution to meet the needs of the campus.

Additional options exist to scale up the potential power of the stream. By diverting water into a penstock we can raise the static pressure at the point of the turbine, thus increasing the kinetic power. Increasing the height of the dam would also increase the gravitational power extractable from the stream. There could be various ecological repercussions resulting from the manipulation of the stream. For example, raising the dam might increase turbidity or effect defused O2 concentrations.

We observed several fish in the reservoir behind the dam. If a hydroelectric system is installed which has all the water passing over the dam going through a turbine or wheel, the migration of fish over the dam would be effectively blocked. Whether the fish community is made up of permanent residents of the reservoir and/or drainage pathways upstream of the reservoir or got there by jumping the dam is a mystery. The necessity for having fish able to get back and forth over the dam is therefore unknown. If the fish need to get over the dam, then they would be adversely affected if the stream went through a turbine.

We saw that fluctuations in volumetric flow roughly correlated to rainfall variations, as predicted inthe hypothesis for Q2 [19]. Because of this we chose not to average the potential power of the stream, and instead gave a range. It is important to note that electrical output will likely fluctuate greatly between the wet winter and dry summer seasons. This fact becomes important when considering the type of hydroelectric system we would need to harness the stream.

There were several limitations that might have influenced the outcome of this investigation. The inherit variability between flow measurements with the current meters is the largest uncertainty. Furthermore, it was impossible to ensure that measurements began and stopped with the stop watch, thus there is some variability in the duration of each reading. The magnitude of these uncertainties are less than a second for each minute timing interval, and we tried to minimize possible errors. To compensate for variability of flow measurements we took multiple readings, and used average velocities for our final data analysis. We also announced the remaining time left for each reading at the 30, 15, 10, and last five seconds. This practice helped measurers anticipate the end of each reading, which hopefully resulted in more accurate timing.

Determining the Cost of Installing a Hydro System

The cost of installing a pico hydro turbine, one designed for flows below 500w, has not been determined. We discussed a variety of different possible hydroelectric systems. A promising system involves a low head/low flow Banki turbine, which would utilize the existing structure of the site and would have low installation cost. Unfortunately, it has been very difficult to locate a manufacturer of pico hydro Banki turbines.

Another approach involves the 500w pico hydro turbine designed by Lotus Energy, a Nepalese company [17]. This model features a built in alternator on the same frame as the propeller, which would make it suitable for charging batteries, but could easily be converted to feed directly into the grid. Unfortunately, we have been unable to contact Lotus Energy, and thus we have no information on the efficiency of the turbine, or the cost of installation and maintenance.

A long pen stock is another way to harness and maximize the hydroelectric potential of a stream. Water would be diverted from the stream to flow down a pipe, which would travel as far downhill as possible. The water would be forced out of a nozzle at the bottom of the pipe at high pressure and speed. An impulse turbine would be turned by the blast and connect to an alternator which would generate electricity. A pen stock would have much more impact on the environment than a run of the river system. Water would be removed from the stream until it came out of the bottom of the pen stock. There would be a pipe running a distance downhill.

According to topographic maps, the culvert is 125 feet above sea level. There are 2 likely routes for the pipe to go downhill. The most direct route to sea level would travel ½ of a mile, but the turbine would not be near established electric lines. If the pipe approximately followed the stream, it would reach Puget Sound in 2/3rds of a mile and the turbine would be relatively close to established power lines, since the campus runs a community school there. The cost of the difference in lengths of the pipe will likely be less than the cost of running electrical lines to the site of beach closest to the culvert, so following the stream is likely a better option.

Larger diameter pipe increases the flow capacity through the pipe but is more expensive; a good balance for a typical (minimum on our record) flow rate is a 3 inch diameter [20]. Market prices for 3 inch PVC are about 1$ per foot, which for 2/3 of a mile comes out to about 3,500 dollars (Google). Friction loss for about 100 gallons per minute going through 3 inch PVC would be about 0.72 feet of head equivalent for every 100 feet of pipe, which totals about 25 feet of head lost over 2/3 of a mile of pipe. That would leave about 100 feet of effective head producing pressure coming out the bottom. Using a potential energy equation during low to average flow rate, Potential energy per second =mass per second times gravitational acceleration times head, we get 2400 watts. Assuming a 60% efficient impulse turbine was used and 1 gallon per second was diverted from the stream, it would produce about 1450 watts, or about 1.4 average households worth of power (21).

Maintenance of the hydroelectric system is anticipated to consist of replacing the brushes and bearings on the alternator about once every two years, the materials for which will cost about

50$ and will take about an hour of labor, though this is dependent on the system we would choose to install.

Future

After our research of the hydroelectric capabilities on The Evergreen State College, we have come to the conclusion that our understanding of the streams on campus is incomplete. Future investigations must be conducted which include a more detailed exploration into the ecological effects caused by raising the streams head or adding a hydroelectric installation. We have an understanding of the potential power we can generate from the stream in the winter, as well as ways to increase it. We do not know if it makes economic or ecologic sense to utilize that power nor do we know how low summer flows will affect the hydroelectric capacity of the stream. However, it is our recommendation that a student group, or class expand upon the knowledge we've worked to collect. Ideally we would like to see the building of a hydro-system; there is great opportunity for unique learning experiences. We would like to keep the construction and installation of a hydroelectric components local, in order to keep installation and construction cost low, and to develop a capacity to maintain a hydroelectric system on campus.

We have discussed a few applications for this power source. One idea borrowed from Tibetan Buddhist traditions would involve installing a prayer wheel at the installation site. The wheel would depict prayers, mantras, and symbols with the idea being that the effect of spinning the wheel would be the same as orally reciting a prayer. Water that touches the wheel is said to be blessed. While the idea is appealing we question whether the non-secular nature of the wheel will alienate or unify the Evergreen community.

Another idea would involve transmitting the power from the stream to the Daniel J. Evans Library at Evergreen. This could be used to power some of the artistic lights atop the building, making a nice public relations statement. The fickle output of the stream and the costs and inefficiencies of transmission make this idea difficult if not infeasible.

There are many other ways that the stream could be utilized. The College may agree to other possible uses, or decide to leave the stream as it is.

Works Cited

[1] Sinclair, John A. "Assessing the Impacts of Micro-Hydro Development in the Kullu District, Himachal Pradesh, India." Mountain Research and Development 23 (2003): 11-12. JStor. TESC, Olmypia. Keyword: microhydro.

An investigation was conducted to define the social, economic, and environmental impacts of micro-hydro development in the Kullu District, India, an area characterized by little industrial development. The effects of the micro-hydro were minimal on the behavior of the local populace. The practice of collecting firewood remained unchanged by the increased supply in electricity, which was one of the original intensions of the installations. Furthermore, the turbines were installed predominately by Nepalese laborers, with little economic benefits transferring to the local populace. The environmental impacts were not an overriding anxiety; however some concerns were raised including environmental damage associated with access to the construction sites, stream diversions, etc. This article provides an example of the impacts of micro hydro upon local ecosystems, economies, and people.

[2] "EEON Plot Locations." Map. Evergreen Ecological Observation Network. TESC. <http://academic.evergreen.edu/projects/EEON/EEON_PROGRESS_MAP.jpg>.

A source used to indicate the potential hydroelectric installation sites. It is a map of the area around TESC and includes streams and different ecological zones.

[3] Issacs, John D., and Walter R. Schmitt. "Ocean Energy: Forms and Prospects." Science 207 (1980): 265-273. Jstor. TESC, Olympia. Keyword: microhydro.

Different energy sources of the sea are discussed as potential energy sources, including wave, currents, tidal, and temperature and salinity gradients. Explains the hydrologic cycle. Not of great use in relation to micro hydro power, but it provides reliable background knowledge.

[4] Zhongwei, Guo, Xiangming Xiao, and Dianmo Li. "An Assessment of Ecosystem Services: Water Flow Regulation and Hydroelectric Power Production." Ecological Application 10 (2000): 925-936. Jstor. TESC, Olympia. Keyword: Hydroelectric.

This was an assessment of the water regulating capabilities of terrestrial ecosystems along the Yangtze River. The research group investigated water flow regulation by major processes such as canopy interception, litter absorption, and soil/ground water conservation. The results are substantial, indicating that the economic value of the terrestrial ecosystems is outweighed by their capacity to regulate flow rates. The information is relevant to the forest surrounding streams on TESC campus.

[5] Little, John D.C. "The Use of Storage Water in a Hydroelectric System." Journal of the Operations Research Society of America 3 (1955): 187-197. Jstor. TESC, Olympia.

This source describes methods for using storage water in hydroelectric systems with uncertain future flow rates. It was written for large hydroelectric systems, and may be irrelevant in relation to the small flow rates of streams around TESC. It does reinforce the assumption that there is increased flow during spring.

[6]"Micro-Hydropower Systems - a Buyer's Guide." CanRen. 30 Apr. 2004. Canadian Resources. <http://www.canren.gc.ca/prod_serv/index.asp?CaId=196&PgId=1305>.

A buyer's guide to micro hydro. The website list introduces the idea of micro hydro including the principle components of a system. Also describes ways to estimate how much power and energy you need. It is a good source with immeasurable relevance to this investigation.

[7] "Olympia Weather - Washington - Average Tempurature and Rainfall." County Studies.Us. 2003. Federal Research Division of the Library of Congress. <http://countrystudies.us/united-states/weather/washington/olympia.htm>.

Precipitation and temperature measurements for Olympia, WA; this source was used to estimate precipitation during the investigation. November through January was the heaviest months while July experienced the lightest rainfall.

[8] Hoare, Robert. "Olympia Priest PT PA, WASHINGTON USA." World Climate. 2008. Buttle and Tuttle Ltd. <http://www.worldclimate.com/cgi-bin/data.pl?ref=N47W122+2200+456109C>.

Another website with precipitation data; it has measurements in mm and inches and verifies previous findings that indicate that rainfall is heaviest between December through February. July and August were the driest months.

[9] "Olympia Weather | Olympia WA." - Local Information Data Server. 2006. National Weather Service. <http://www.idcide.com/weather/wa/olympia.htm>.

More weather measurements. The raw data comes from the following sources: United States Census Bureau, Federal Bureau of Investigation, National Climatic Data Center, National Oceanic and Atmospheric Administration, and National Weather Service. Based on those sources the data seems reliable. The website verifies previous findings indicating that rainfall is heaviest from December to February, and lightest in July. Annual precipitation is close to 50 inches. This data was used to estimate the correlation between rainfall and volumetric flow in the stream.

[10] "DoradoVista Small Hydropower, Micro Hydro and Water Turbines." Dorado Vista. 2008. DoradoVista, Inc. <http://www.doradovista.com/DVPower2.html>.

Dorado Ranch had plans to install a small hydro power system which would produce surplus power which could be sold to the grid. Useful as a case study of a micro hydro system.

[11] "Small-Hydro Atlas." Small-Hydro. IEA Hydro Power. <http://www.small-hydro.com/index.cfm?fuseaction=welcome.whatis>.

Developed by the Small Scale Hydro Annex of the IEA's Implementing Agreement for Hydro power Technologies & Programmers. Useful information on the power range of small scale hydro. Useful definitions and vocabulary terms contributed to the groups overall understanding of hydroelectricity. Gives a clear procedure for installing a hydroelectric system, from Reconnaissance surveys and hydraulic studies all the way to ownership and maintenance.

[12] "Micro Hydro Power - Pros and Cons." Alternative Energy. 26 Oct. 2006. AEoogle. <http://www.alternative-energy-news.info/micro-hydro-power-pros-and-cons/>.

This source identifies the pros and cons of micro hydro and gives a cost estimate for installations ranging from 1000$ to 20,000. The website also has links to resources on micro hydro as well as comments from informed individuals.

[13] "Water Power." Other Power. 2004. Force Field. <http://www.otherpower.com/otherpower_hydro.html>.

Home brewed micro hydro technology manufactured from a car alternator and a homemade banki turbine. A site which recommends using a water wheel instead of a turbine for small-scale projects, as they are relatively simple and also very efficient.Something Interesting: I found no mention of the idea of using rainwater directly for power generation. It either is very hard to find, or I may be the first to come up with this idea and seriously consider it. Makes me feel either very smart or crazy, I'm not sure which.

[14] Klunne, Wim Jonker. "Micro Hydro Web Portal." Micro Hydro Power. 11 June 2002. <http://microhydropower.net/>.

A website on micro hydro developments. It includes references to hydroelectric companies, book resources, and tutorials. It is very useful. It must be out of date because one of the hydro electric companies they referenced did not respond to any attempts at making contact.

[15] "HYDROELECTRIC PROJECT HANDBOOK." Ferc.Gov. Apr. 2001. Federal Energy Regulatory Commission. <http://www.ferc.gov/industries/hydropower/gen-info/handbooks/post_licensing_handbook.pdf>.

This website is a resource for laws involved in establishing hydroelectric installations.

[16] "Simple Home Built Waterwheel." OtherPower.Com. 2000. ForceField. <http://www.otherpower.com/otherpower_experiments_waterwheel.html>.

A do-it-yourself oriented site on alternative energy solutions. The home built waterwheel idea is similar to what we originally imagined installing.

[17] "Lotus Energy." Lotus Energy. Lotus Energy. <http://www.lotusenergy.com/>.

Lotus energy is a Nepalese based company that manufactures a variety of renewable energy components. Their site features a 200w and 500w turbine which would be suitable for a low impact hydroelectric system. Unfortunately they have not responded to any emails.

[18] "3" Pvc Pipe - Google Product Search." Google.Com. Google.Com. <http://www.google.com/products?q=3%22+pvc+pipe&btnG=Search+Products&show=dd>.

This was just a simple google search for market prices of 3 inch pvc pipe.

[19] "History : Weather Underground." Weather Underground. 05 Mar. 2008. The Weather Underground, Inc. <http://www.wunderground.com/history/airport/KOLM/2008/1/1/CustomHistory.html?dayend=5&monthend=3&yearend=2008&req_city=NA&req_state=NA&req_statename=NA>.

Olympia rainfall records for the period we measured the stream.

[20] Real Goods Company. 1991 Alternative Energy Sourcebook. Real Goods Trading Corporation, 1991. 72-75.

This book had lots of useful technical information regarding small-scale hydroelectric systems, particularly pen-stocks.

[21] Elert, Glenn, ed. "Power Consumption of a US Home." Hypertextbook. 2003. <http://hypertextbook.com/facts/2003/BoiLu.shtml>.

This page had useful estimates for power consumption of an average US household.