As indicated in the call for proposals, your participation in the undergraduate research symposium in the Spring of 2012 to present your research findings will be required. For more information about this program, please visit <http://undergradresearch.nd.edu/>. Also, at the conclusion of your project, you will be asked to submit a final report to the NDEC/SEI Office that includes a brief overview of your project, your research findings, and a list of any publications that may have resulted from your work.

Introduction

We are on an unsustainable march towards draining our earth’s traditional energy sources and poisoning ourselves in the process.  I am now focusing my studies in the hopes of finding and deploying renewable resources to drastically change the destructive path we are on.  My interest in environmental issues emerged from a high school science curriculum that emphasized our multiplying environmental perils.  At The University of Notre Dame, I have decided to couple this interest with my abilities in the sciences and study towards a civil engineering degree with an environmental concentration.  Last summer I continued my Notre Dame studies in Spain where a course on Global Sustainability focused on the timeline of earth’s non-renewable resources.  Our exponentially increasing population and exponentially decreasing natural resources have us on a collision course.  The second half of last summer, I worked for an environmental awareness non-profit organization, where I learned more about how we are poisoning the environment through the course of our everyday lives.  These experiences have inspired me to focus my education and aspirations beyond on clean, safe, and renewable energy.

Traveling thousands of miles to a rural third world country may not have seemed like the best idea at first. But it was actually the perfect place to study how we can meet a population’s energy needs without damaging the environment.  Nepal is poor, mostly made up of rural villages and lacks an infrastructure that we are accustomed to in the West.  To deliver clean power to the people, innovation and low cost are prerequisites.  Notre Dame’s Civil Engineering Department proposed a solution for this situation.  It is called micro-hydro electric generation; or very small scale power generation that can serve small towns and villages without the need for massive and wasteful power distribution.  Political and established industry conflicts prevent us from performing this research in more developed parts of the world.   What we have learned trying to develop this solution in Nepal, although on a small scale, can hopefully pave the way to meeting greater power needs elsewhere in an environmentally friendly and sustainable way.

Going to Nepal was the first stage of this environmental project. I embarked on this exotic journey with the objective of finding a river or stream in a small, rural village that could provide enough water for an effective micro-hydropower system. This trip was coordinated by a Notre Dame design professor, Ann-Marie Conrado, her Nepali-born husband Devi, and several other Notre Dame students that were going to work on various other projects. After much field work, Devi’s hometown village, Chitepani, was determined to be an ideal location for the turbine system. Chitepani has approximately forty households within its village and is located to the east of Pokhara, the main trekking base in Nepal. This site was chosen for many reasons. First, it was a village that experienced significant amounts of load sharing during the dry season. “Load sharing” is a program set up by the Nepali government in order to “share” power so that everyone in Nepal who has access to power can expect to have power for at least part of the day. If a town, village, or area is experiencing “load sharing,” they do not have power at that time. In the dry season load sharing is significantly more frequent and may last longer than in the wet (monsoon) season. The second reason Chitepani was chosen is because of its location on a hill, and the large number of springs and rivers running through it. “Pani” is actually the Nepali word for “water.” The large elevation drop provides for a large head and flow rate, which are crucial for successful micro-hydropower systems. The last reason the site was chosen was because Devi grew up in that village. Even though he moved to the United States when he married Ann-Marie, he started a non-profit computer center in the village that educates the residents, many whom are illiterate, on basic computer skills that could help them become employed in the nearby city. Devi’s annual presence in the village is a great connection and a positive aspect to installing hydropower in Chitepani.

My simple objective got a lot more complicated once I began interacting with the people and interviewing them about their lifestyles, power uses, children’s education, and economic situations. After many translated questions, cups of hot tea, and bowls of noodles, I realized that I was no longer just a researcher. I had assumed the elevated role of someone whom they hoped was going to bring economic relief, increase children’s capabilities in school, and create a stronger bond in the community, along with providing an economical and sustainable power source. The average villager spends about $1.25 (U.S.) a month on government power. However on a night when they are experiencing load sharing, the villager will spend about $1-$2 on kerosene and candles every night. As $1 may seem insignificant to many residents in the United States, in a third world country like Nepal, $1 is worth a significant amount. Alleviating load sharing, especially at night, would allow children to study and do homework later into the night as well. In addition, installing a hydropower generator requires constant routine maintenance and check-ups to make sure everything is in working order. To greatly reduce costs, it would make sense if the villagers were taught how to operate the system and maintain it themselves. After sitting down with the most respected villager (there is no sub-government in this village), I was informed that the villagers would be more than happy to create a council that would meet monthly to discuss the status of the turbine and appoint a villager to maintain it for the month. This positive feedback gave us the inspiration to work even harder to develop power for the villagers.

With our general area determined, a specific site needed to be decided on. One of Devi’s childhood friends is also a licensed trekking guide. He grew up in Chitepani and spoke English fairly well, so he was a good candidate to show us all of the water sites in the area. Out of the seven sites that we hiked to, four fit the criteria we had for hydropower implementation. Our pre-determined criteria were that each must have had: water running all year, a significant amount of water running, a steep slope, and close proximity to the village.

The first site that matched the qualifications was a spring located at the top of the hill that Chitepani is located on. All of the water coming out of the spring is immediately channeled into tanks. From the tanks, the water traveled through four pipes. These pipes took the spring water to different villages in the area, including Chitepani. If this site were to be used, we would have to use the water that was already in the pipe. Since this water is the only drinking water source for the area, villagers are extremely protective over this site

The second site that matched our criteria was another spring that was located a little closer to the village than the first site. The water from the spring collected in about 1.5 meter diameter pools that were used for swimming in the village. The water would run off the hot-tub sized pools, fall about 2 meters, and then land into another pool of similar size. The fact that the water was falling about 6 feet at a 90 degree angle yielded great potential for a hydropower system.

The third site was a river called the Soto Khola that ran in the valley between the hill that Chitepani was located on and the hill next to it. It is a little closer to the village center than the first 2 sites. The Soto Khola always has water flowing, but during the rainy season the river is about 5 meters wide, while during the dry season it ranges from 1 meter to .25 meters wide. The water that flows through the Soto Khola is considered clean enough for drinking.

The fourth site that we considered was a stream created by the runoff water from the village. All of the water that came from the houses collected about 300 meters away from the village center and emptied into the Soto Khola about 750 meters away from the village center. The fact that this water was runoff water meant that the flow rate did not change much during the wet or dry season. The stream also follows a very steep path that could provide for a large height drop. The stream was about 30-50 centimeters wide. The stream ran through farmland, but was rocky towards the mouth.

For the second, third, and fourth sites we performed head and flow rate tests. We could not perform tests on the first site because the water was in a closed pipe the entire time. To find the flow rate at that particular site, we used the float method. We measured the depth of the stream at different locations, the length of a certain portion at the site, and then timed how long it took a float to travel the measured portion. The timed test was done multiple times, and then the times were averaged to get the most accurate data. The head was measured by using clinometers. We measured a distance, and then using clinometers, measured the angle of the ground. In order to get the head, we used trigonometric equations. In order to get the flow rate, we found the cross sectional area of the stream using the depth and width measurements and then multiplied them by the averaged velocity of the pipe.

After finding the flow rate and the head of sites two, three, and four, we used them in the power equation to find the maximum power potential of each site. The equation for this is simple. One must multiply the flow rate, the head, the gravitational constant, and the loss factor, which is generally .7 for micro hydropower. The third site had a high maximum possible power output of about 3.3 kW with only one meter of head. The other two sites had about 0.5 kW with a larger head.

After performing our preliminary calculations, the third site (Soto Khola) was the front runner. We reviewed the pros and cons of using the Soto Khola as our hydropower site. It had a high flow rate, which was very important, because if we needed more power, we only needed to increase the head a little bit to get a large power increase. Sites two and four had a substantially lower flow rate, which would require a large increase in head to increase the power output. Increasing the head is often expensive because it requires more pipe to be installed. It also yields a larger head loss because of the friction of the pipe. If we increased the head by a factor of two on the second site, the maximum power output would be around 6 kW, which was our original goal. A positive aspect about site two was that it was fairly close to the village. The closer the site is to the center of the village, the lower the cost of installation of power lines is. Also, a closer site means less loss of power during transportation.

Yet there were obviously some drawbacks to using the Soto Khola as our hydropower site. Soto Khola has a lot more water running through it during the rainy season. The turbine could either be built to be adjusted to handle different amounts of water, which could cost a lot more money, or could be removed or turned off when there is too much water. Since our main concern is delivering power during the dry season, we would have to build the turbine to handle the low flow rate in the dry season, not the wet season, even though there is a much higher maximum power output potential. Another issue with the flow rate dramatically increasing in the wet season is the toll it will take on the turbine. We plan on installing a micro hydropower system that is small and probably fragile. High flow rates have a great potential of ruining or damaging the system. In addition, after talking to villagers, Sota Khola does not have just water flowing during the wet season. The river is usually flowing with muddy, debris-filled, water slurry. Large amounts of mud and other foreign objects can only harm the turbine. The only solution to all of these problems would be to remove the hydropower system completely from the river during the wet season which lasts about two months. Since the village will have more power from the government during this time, it won’t have a great effect on the villagers, but we would have to make sure that there is someone trained well enough to handle the attachment and detachment of the system every year.

After taking the field measurements and doing the basic power calculations, we traveled back to the village to talk to the villagers about power use. After talking to the villagers more, we realized the Chitepani inhabitants had a much bigger problem than a lack of power. A major problem is that during the wet season, mud gets into their water supply, making their water undrinkable. For two months out of the year the people in Chitepani do not have access to clean drinking water. A reliable power source would increase the quality of life of the residents of Chitepani, however, clean drinking water is vital to survival, and therefore takes precedent. Since the exciting discovery that the Soto Khola could provide the kind of power output that we were looking for, site one had not really been on our mind for a while. However, after learning of the importance of clean drinking water to the villagers, a new idea occurred to us. What if we used the water in the pipe of site one that was carrying the spring water to Chitepani to generate hydropower? Since the water needed to be filtered before it entered the system anyway, maybe we could install a more specific filter. Hopefully we would be able to filter the water to an extent that would make the water drinkable all year around. We could generate hydropower AND provide clean water to the villagers.

Site one had a lot of things going for it besides the possibility of providing year-round clean drinking water. Not only would the water already be in a pipe, which is half of the process of installing a hydropower system, the spring was located about 300 meters above the village. This provides 300 meters of head, which is a lot greater than the one or two meters we were looking at before.

Since there is no government in small villages like this, we approached the most prominent villager with our idea. He is the one who takes time to know everyone living in the village and shows deep care for their well being. We anticipated a little hesitation when telling him that, in order to install the hydropower system and filter, we would need to cut off the villager’s water supply for a few days. He laughed and said in Nepali, that the villagers would be more than willing to use a back up supply of water for a few days. He shrugged it off like it was no big deal. The fact that the villagers were on board with us tampering with their water supply was exciting news. Now all we had to do was build the turbine.

Our first order of business once we returned to the United States would be to contact Dristy Shrestha. Dristy is a Middlebury College student from Nepal. Last year she worked on a similar project, bringing micro-hydropower to an impoverished village in Nepal. I found out about her from her blog (<http://microhydropowerpeaceprojectnepal.blogspot.com/>). She successfully delivered micro hydropower to 37 houses, which is similar to our project. I was hopeful that she would have some insight on my project, and give me the heads-up on what I should avoid and certain things that I should do. Dristy not only had great advice on how to incorporate the villagers into the project installation, but she also had numerous contacts that could be helpful along the line.

I also contacted a filter company whose Vice President is a family friend of mine. I am now realizing more and more how useful contacts in the real world are. I hoped that he would be able to steer me in the right direction of which filters to buy and where to buy the most economical ones. The vice president informed me about slow sand filters, or biosand filters. This kind of filter is used in third world countries extensively, and is very effective, cheap, and easy to install. Its basic materials consist of a tank, sand, gravel, and PVC tubing.

The next step would be to calculate the flow rate of the water traveling through the pipe when it reaches the center of the village. We needed to use many assumptions to make this calculation. First, we had to estimate the length of the pipe from the spring to the village center. Walking along the road, the distance was about 1.1 kilometer, but maps show that a straight line between the two locations is about 0.7 kilometers. Because we assume that the pipe probably has a length somewhere between 1.1 and 0.7 kilometers, I performed loss calculations of a pipe that is about 800 meters long and a pipe that is 1 kilometer long. The next assumption that had to be made was the amount of bends and turns in the pipe. It is certain that the pipe is likely not a straight line from the source to the village due to the terrain. Just from looking at the source, it was clear that the pipe went underground at some point.

In any pipe there are major and minor energy losses, especially in one that is 1 km long, which is the length of the pipe that we are dealing with. Major energy losses are due to the friction or roughness of the pipe, and occur over the length of the pipe. Minor energy losses are the losses that occur at a given point; a bend, joint, valve, etc. In order to find the major losses of the pipe, we need the friction factor of the pipe, *f* , the length of the pipe, L, the velocity of the water in the pipe, V, the diameter of the pipe, D, and the gravitational constant, g. These values are used in the equation below

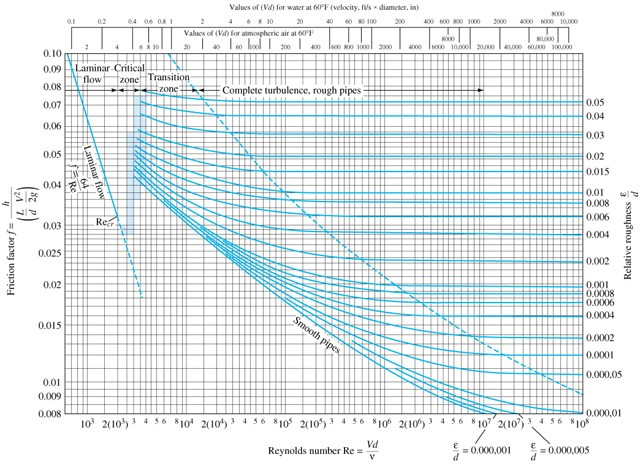
h_f = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g}

(equation 1)

The friction factor can be found using the Moody chart, which is shown below. The friction factor is on the left side, the ratio of equivalent roughness for new pipes and the diameter are on the right side, and the Reynolds Number is on the bottom. In order to find the correct friction factor in the experiment, the Reynold’s Number is needed. The value of the Reynold’s number can tell a person whether the flow is laminar or turbulent. The higher the Reynold’s number, the more turbulent the flow is. According to The Fundamentals of Fluid Dynamics, by Munson, Young, and Okiishi, if the Reynold’s Number is less than 2000, flow is considered laminar. Similarly, if the Reynold’s Number is greater than 4000, flow is considered turbulent. The equation for Reynold’s Number is below

 (equation 2)

In the above equation, {\rho}\, is the density of the fluid, and μ is the dynamic viscosity of the fluid. For our project, there are 2 unknowns in this equation, the Reynolds number and the velocity of the water. Without the Reynolds number, we cannot calculate the friction factor or the velocity. However estimations can be made. Looking at the Moody chart (below), we know that the flow in the pipe has to be turbulent, as most downhill pipe flows are. Also, since this experiment will assume the worst-case-scenario, we will look to the right of the moody chart, the more turbulent side.



**Figure 1:** The Moody chart used to find the friction factor of a fluid.

After looking up the relative roughness factor for PVC (.0015mm), and dividing it by the inner diameter of the pipe (The outer diameter was calculated to be about 3.34 cm, but in this calculation we will assume that the pipe has a thickness of .2 cm, so the inner diameter is 2.94 cm or 29.4 mm) The ratio comes out to be more or less 0.00005. Matching this up to the friction factor, we can estimate that the friction factor is around 0.0125. Even though we now have an estimated friction factor, we cannot estimate the Reynolds number. This is because the Reynolds number varies greatly over the portion of the chart that we are looking at. This means we do not know the velocity and cannot find the head loss.

There is another equation that can help us find the velocity.

 (equation 3)

Where  is the initial pressure,  is the specific weight in water,  is the initial velocity of the water, is the initial height of the water,  is the final pressure of the water,  is the final velocity of the water,  is the final height of the water,  is the head loss due to friction of the pipe,  is the head loss due to the turbine, and,  is the sum of all of the minor losses in the pipe with  being the loss coefficient for the pipe component. For derivation equation 3, see chapter 8 in Fundamentals of Fluid Dynamics by Munson, Young, and Okiishi.

Ignoring head loss due to the turbine and minor losses, equation 1 is able to be completed, save one variable; velocity. Setting , , ,  equal to zero, equal to 300.75 (300 meters is the elevation difference from the spring to the center of the village, and .75 is the approximate height of the tank of water at the top of the spring), g=9.81 m/s2, L= 1000 meters, D= .0294 meters, and *f* is .012. With these values, a quadratic equation needs to be solved. The simplified equation came out to be 300.75=20.9145, solving for V, the velocity came out to be 3.79 m/s, therefore the flow rate is equal to .010277 m3/s. In my calculations, I added minor losses using equation 3. I probably over compensated, but I assumed that there were 10 90 degree threaded turns in the pipe, 15 45 degree threaded turns, 5 90 degree long radius threaded turns, one globe, one open gate, and one open angle. The loss coefficients for the pipe components were all found in the textbook. With all of these loses, the velocity degreased to 3.64 m/s and the flow rate to 0.00986 m/s. This is not too significant of a change from the initial velocity, but will help when we are trying to buy the correct turbine and determine the maximum power potential.

If we assume that the minor and major losses are similar to the ones calculated (above), then we can use the flow rate for the estimated power output. The equation for power output is simple and shown below (equation 4)

 (Equation 4)

P is the estimated power output in watts, H is the head height, in meters, g is the gravitational constant, and e is the efficiency factor. The efficiency factor for micro hydro systems is about 0.7, according to the article Micro-Hydropower Systems by Natural Resources Canada. When calculated, the estimated power output is a lot smaller than we were hoping; less than 1kW. This was disappointing, but did not deter us from using this site. We still thought that the proximity of the pipe to the village and the fact that water was already in a pipe were advantageous compared to the other sites.

One of the things we learned while talking to villagers was that everyone wanted a T.V. Only a few villagers actually had televisions, but many said that they would buy one if they had more power to use it. That made me a little uneasy. One of the main reasons for providing power to the village was so that the children could have more time to study at night. However with a television, they would not only decrease their time devoted to their studies at night, but during the day also. Installing power in the village would yield less time devoted to studies, as opposed to more.

To solve the problems of a small amount of power and increased television usage, I proposed a solution. Instead of wiring every house with new power lines (the government won’t let us touch the current power lines), we could use a pelton turbine, installed in the pipe delivering spring water, to generate power to charge batteries. These batteries could then be used in portable LED lanterns. Each house can get a lantern or two and this way will have portable, cheap power.

Because the batteries can only be used for the lanterns, we will ensure that there is not an increase in television watching. The lanterns also will help us save resources. We will no longer need to install power lines to every house. Installing power lines is not only a big expenditure, but will induce power transportation losses that would need to be accounted for.

As I looked into the possibility of this, I came across a man named Mitchell Silver of Silver Software Inc. Mr. Silver has lived in Nepal for about 9 years and has installed a similar system in various villages. Mr. Silver provided remote villages with lights in the form of lanterns with rechargeable batteries. On the contrary, Mr. Silver used solar power instead of hydro power to fuel the battery chargers. A few e-mails and a phone conversation later, Mr. Silver has given us valuable advice, a contact of a Nepalese pelton turbine manufacturer, and a boost of confidence that our idea was indeed possible.

The next step of our project was to find a lantern that is suitable for the lifestyles of the Chitepani villagers. Black Diamond Equiptment Ltd. manufactures a lamp that is ideal for this situation. Called the Apollo Lantern, it is LED, and lasts up to 60 hours. It has handles that can be turned over into a stand for the lantern (shown here <http://www.blackdiamondequipment.com/en-us/shop/mountain/lighting/apollo-lantern/>). It runs on NiMH batteries, which are also rechargeable. Black Diamond Equiptment Ltd also manufactures a charger for these batteries.

Mr. Silver explained that he was able to create a system for the villagers to cooperate and charge their batteries in an effective system. The solar panels were installed in one family’s house, and this is where the chargers were too. A schedule was made of who could charge their batteries on each day of the week. When it was someone’s “day” to charge their batteries, they would drop off their batteries outside the charging house in the morning. The people living in the house would connect the batteries and have them fully charged for pick up that night. The people living in the house did not get paid, but they did have an incentive. There was also a cell-phone charger installed from the solar panels. The people living in the charging house could charge their cell-phones and other villager’s cell phones for a small charge.

Mr. Silver’s plan was good and effective, but may not work in Chitepani. We discussed it and decided that since the turbine would not reside in a family’s house, we would have to appoint someone to be in charge of the batteries. If we can get enough funding, I would like to set up some kind of payment system. Ideally, we can get the lanterns and chargers for free. Then we can sell them to the villagers. This will provide a feeling of ownership for the villagers. With the money we collect from the lanterns, we can pay someone a small fee to monitor the turbine and charge the batteries. The money can also be used for maintenance costs as well.

Contact was made with a lot of different turbine manufacturing companies in Nepal and India. Hopefully we will be able to agree on a design and a price that will best suit our project. The next step will be to actually purchase a turbine, lanterns, and the battery chargers. Then we would hook up the system and test it in St. Joseph’s River, located close to the Notre Dame campus. Once we have it up and running to our satisfaction, we will return to Nepal to install the system and teach the villagers how to use the lanterns, how the turbine works and set up a maintenance schedule. Only through the help and support of future donors can this project accomplish its goals.