Panamanians: Left in the Dark

An investigation of feasibility for hydroelectric power generation in Piriatí, Panama

"Cultivating grassroots solutions to bring electrification to developing communities and enrich the well-being of our global neighbors."

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An investigation of feasibility for hydropower electrical generation in Piriatí, Panama

Michigan Technological University
International Senior Design
Summer & Fall 2011

Submitted To:
Michigan Technological University
On November 18, 2011

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Create the Future

Disclaimer

This report, titled "Panimanians Left In The Dark: Micro-hydro in Piriatí Panama", represents the efforts of undergraduate students in Civil, Mechanical, and Electrical Engineering at Michigan Technological University. While the students worked under the supervision and guidance of associated faculty members, the contents of this report **should not** be considered professional engineering.

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1.0 Executive Summary

Approximately 1.6 billion people in the world currently live without a consistent source of electricity, according to recent global poverty statistics (Shah 2010). The present feasibility study observes and identifies the needs of Piriatí Emberá, a rural village comprised of an indigenous people in eastern Panama. Tim Burke, a former Peace Corps volunteer, provided a proposed design and preliminary introduction to hydropower generation for Piriatí prior to the assessment trip in August 2011 (T. Burke 2009). This document provided an introduction to the status of the village and the waterway that runs adjacent to Piriatí. After researching the topography of the river and the community, it was found that several sites along the river would be adequate for use in hydropower generation. Data was collected from each site, including analyses such as flow rates and global positioning system (GPS) points. Several sites along the river were identified as sites of potential electrical generation. Two primary sites, Cascada Pequeña and Alan's Falls, would be satisfactory in providing more than 5 kilowatts of power for the community of 120 homes and 500 people. While Alan's Falls and Cascada Pequeña would have very similar turbines, generators, and electrical transmission and distribution systems, the site designs are quite contrasting. Alan's Falls would utilize a longer penstock and diversion system, and yields a slightly higher power potential, though it is a further distance away from the community, which is associated with higher costs. The Cascada Pequeña system would require the construction of a trench for water diversion that would bring the generation site close to the community. The Alan's Falls site is the primary site of recommended design for the community, and the Cascada Pequeña design is an alternative and secondary recommendation. Further analysis showed that more information on the river's seasonal flow will be needed in order to design the most efficient system that will maximize power output.

2.0 Introduction and Background

The use of diesel generators as a source of basic electrification has been fundamental in providing power to rural communities worldwide. However, as supply and demand causes the cost of diesel to inflate yearly, families and communities whom live on less than $100 per month per household find themselves paying out as much, or more than they make, year after year.

Piriatí, Panama is a small village located in eastern Panama. It is comprised of approximately 500 people and 120 households. The community currently houses a 15 kilowatt diesel-run generator. The generator was placed in the community over fifteen years prior to the team's assessment, and has been noted to break down often. As diesel costs inflate in Panama, the community can only afford to generate approximately 9 hours of electricity per week. In addition, the current electrical distribution system provides power to less than fifty percent of the homes in the community.

The community is comprised of an indigenous tribe of people of Panama known as the Emberá. The Emberá have several tribal communities located throughout much of eastern Panama, and a mutual tribal council exists for jurisdiction purposes. The cacique (Spanish for chief) of three neighboring Emberá communities currently lives in Piriatí. He was able to provide insightful information regarding the past endeavors of the community to obtain a reliable energy source.

The people living in Piriatí migrated to the current village over 35 years ago. In 1976, the federal authorities of Panama flooded the Bayano River, located approximately 90 kilometers (about 60 miles) northeast of the Panama City, to create a hydropower dam that would provide electricity to the capital city. Bayano Lake, the end product of the flooding, is the second largest artificial lake in the country of Panama.

The hydropower facility is housed to output a maximum of 150 megawatts and produces 105 megawatts (Econergy International Corporation 2004). Approximately 30 megawatts can provide continuous power for roughly 15,000 households, and so the capacity of the Bayano Lake dam provides about 52,500 homes with continuous power based on the 120 Volts alternating current (AC), 60 Hz frequency system that is also in place in the United States. For comparison, the Hoover Dam, located between Arizona and Nevada, United States, outputs approximately 2080 megawatts and can therefore supply nearly 1.04 million homes or 1.3 million people with continuous 120 V AC, 60 Hz power (United States Department of the Interior, Bureau of Reclamation 2009).

The Emberá people living in the region were flooded out of their native lands and forced to move to a land designated to them by their government. They moved approximately 28 kilometers (18 miles) east of their original location. Even with the inconvenience of relocation, the government of Panama did not offer the community any sort of connection to the hydroelectric dam built on their homelands.

Members of the community still display some resentment towards the lack of initiative of the government in supplying the community with power as compensation for their relocation, and have been trying for several decades to either receive power from the Bayano Lake dam or from the neighboring town of Tortí that lies approximately 13 kilometers (8 miles) to the east of Piriatí.

On most nights, families still find themselves left in the dark, relying on only candlelight for any kind of productivity after sunset. Some families that have a more substantial income are able to generate electricity from personal generators that only run in the evening hours to supplement productivity, though the diesel is still prohibitively expensive. There is an obvious need and desire for an economical, sustainable, reliable, and feasible source of power for use within the community.

One way that the community of Piriatí and the country of Panama have tried to remedy this is by trying to connect the Panamanian electrical grid to the Colombian grid. This would in turn facilitate the construction of an international highway between the two countries. However, previous advancements of the Panamanian highway have led to extensive deforestation of virgin rainforest. Now with the final section of the eastern Panamanian rainforest in jeopardy, many international organizations have stepped in to try and halt the construction of the highway. Other international organizations are also opposed to the international highway for the fear of the spreading of Colombian drug trafficking as well as increased guerrilla violence. Therefore, these international organizations are promoting localized rural electrification via sustainable means such as solar and hydro power. Based on the success of the hydropower project in Agua Fría, more financial attention may be directed to a project such as this one and may allow for a project with a larger budget than first expected. (Alan McDonald, PCV)

Further, the positive effects of introducing power to underprivileged communities have been proven through many case studies in the advancement of rural electrification; improvements could be seen in economic stimulus, medical treatment, and the introduction of refrigeration (Lewis 1997). Refrigeration of goods not only minimizes food and medical wastes within households and stores, but it also increases the ability to exchange and sell perishable items on a much larger scale; in addition, the minimization of waste should also increase net income of households by being able to purchase smaller or larger quantities of items with the capability to regulate use more definitively (Lewis 1997). Other significant advancements could be seen within the educational technology available in the school system. Currently, the community has ownership of one computer that is obsolete to current technology, and internet access is unavailable for computers, though remotely available in some areas for cell phones. The addition of electrical access within the schools would facilitate the possible addition of a technological center for use by children as well as adults; this would help to encourage and facilitate personal and community educational efforts.

Another population affected by the lack of electrical inputs is a smaller and more remote population of Latino farmers that live along the Piriatí River on the southern side of the highway. This population includes less than 30 households and one school building that is also utilized as a community meeting area. Due to Latino land ownership on the side of the river that will be utilized for hydropower generation, this community has requested to be included in the proposed system. The inclusion of these areas was studied on a very preliminary level but should be further investigated. An email from Tim Burke has been included as a digital appendix and can be found on the compact disc. In this email Tim Burke refers to difficulties that arise with land easement for construction projects.

The present document will serve as a feasibility report to provide supporting information to the community of Piriatí for use in deciding on whether or not to pursue a consistent and renewable energy source. The document will cover all data collected while in Panama, the subsequent data analysis performed at Michigan Technological University, and suggestions for future data collection and site design. In addition, project contacts are located in Appendix O; these contacts may be used for future reference. Project contacts are from Michigan Technological University, Panama, and the United States Peace Corps.

3.0 Community Assessment & Data Collection

The data that was collected while in the community of Piriatí was used for preliminary analysis and study of feasibility for each prospective generation site that was identified. Flow rate calculations were compiled, edited, and updated by utilizing watershed delineation.

More information was collected at the closest site, Cascada Pequeña, because it had been identified as a potentially feasible power source in a previous feasibility study. The analysis was completed by author Tim Burke, a previous Peace Corps Volunteer who served in eastern Panama. Due to this initial study, the survey and data points that were collected and examined were mostly obtained in the land area proximal to Cascada Pequeña; these were also used to estimate the actual available head at this site.

The data collected while in Piriatí was necessary for the completion of this feasibility analysis. The overall goals of the data collection while on this assessment trip included:

1. Determine the necessary output of the system for the desired usage of the community.
2. Collect information on the average community member: income, job, number of persons per household, etc.
3. Analyze the financial feasibility and support of the system from a community level.
4. Determine the community satisfaction with the current electrical generation unit and, subsequently, willingness to opt for a new system design.
5. Analyze Cascada Pequeña to verify the potential for a satisfactory electrical output.
6. Document and determine lengths and distances for prospective transmission lines in order to cover desired community areas.
7. Collect topographical layout data of feasibly usable sections of the river and the adjacent banks, while determining relevant flood plain areas.
8. Collect and calculate head and flow rate data for proposed hydropower sites.

In order to properly design a micro hydropower system for Piriatí, the needs of community members had to be identified. Several meetings were held with Guillermo, the cacique (or community leader), and other community leaders. The meetings served to educate the community on the purpose of the team, the project objectives, and to obtain any useful information for the project during in-country data collection.

The Cacique placed much emphasis on the need for electricity, especially for public uses – the school, business opportunities, medical facility— and of course, electricity for homes. A total of sixteen community surveys were completed; nine in the Emberá community consisting of individual families, schoolteachers, and community leaders, and seven interviews were conducted with Latino community members, which consisted of individual families and community leaders.

From these surveys an analysis of how much energy the community needed to provide them with their general request was performed. The analysis came to a power supply of approximately 20 kW. Some of the items included in the power demand analysis include light bulbs, radios, fans, freezers, computers, and televisions. Further details on this analysis can be found in Appendix A: Estimated Power Demand. Included in this process was an interview with a community leader who is primarily responsible for the operation of the diesel generator.

Technical diesel generator information was gathered with the help of Juan, the secretary of the Junta Directiva, or town counsel. Information was collected on the diesel generator through photographs as well as written documentation. Juan started the generator to show the team how it worked for some cases and did not work for others. During the time that we stayed in the community, part of the transmission system had not been working effectively for several weeks, and the houses that were connected on the northern side of the village were not receiving generation from the motor. As Juan climbed onto the transmission pole next to the generator housing in the community, he was able to repair connection through a switch that had been opened (most likely as a safety trip). It was noted to the group that an electrician had been called out to the community, but he was unsuccessful in helping to repair the system when it had gone down.

The generator was hooked up to the community's distribution system. The locations of the poles in this system were recorded with a GPS unit. Elevations and locations of important objects and sites within the community were also collected using a GPS unit. These data points were compiled onto a map and were used to determine distances within the community during the design process. The data was also pertinent because it helped to characterize the river. The geographical information was necessary for calculating and optimizing the potential output of system. Surveying also provided topographical information regarding the adjacent land to the river which was used to accurately calculate flood plain areas, as well as the exact head of waterfall drops, as seen in Appendix B, Table 7: Compiled Site Data.

Since a reliable power source was not guaranteed prior to travelling, the team chose to take an optical theodolite over its electronic successor which runs on battery power and requires frequent recharging. Optical theodolites are very accurate if one is confident reading a vernier scale. The team surveyed the Piriatí River and its banks for a distance of 430 meters until it reached Cascada Pequeña.

The area downstream from the falls was surveyed because it was the initial proposed turbine and generator site. Six inch steel nails and pink ribbon were used to set five survey benchmarks along the river, which the team used as turning points and back sights for carrying the survey up the river. All of these points were marked by the GPS in case the benchmarks would ever need to be located. The findings from this survey can be seen in Appendix C. The potential head for Cascada Pequeña at the proposed generator location was determined using the elevations determined during the survey. If the generator was placed above the flood plain, it would result in a negative head of 0.53 meters but if the generator was protected by a hydraulic structure and placed in the flood plain, it would have a potential head of 1.83 meters. The optical theodolite was only used at Cascada Pequeña since the other waterfalls were much farther away and the team deemed it impractical to haul in the equipment to these other sites.

Along with collecting topographical data, flow rates and river bed cross sectional data were collected to gain more detailed information about the river and the adjacent land. A previously studied waterfall site, Cascada Pequeña, was observed and documented in order to ensure the best analysis for the placement of a potential generator house. Flow rates and height measurements were taken from multiple sites along the river to get a more accurate profile of both the underlying topography and the fall, or characteristic, of the water within the channel.

Flow rates were found using the Float Method. This method consists of a known length of rope pulled taut in the water, used in conjunction with a floating object, usually a stick, leaf, or water bottle. The floating object is timed from the beginning of the length of rope to the end. From this a velocity can be determined and recorded. Due to the variation in the velocity of a river cross section, it was measured at four different stations across the cross-section at approximately 5 feet apart. The actual flow rate depends on the profile of the river; therefore, an average cross-section of the river was calculated along the same route travelled by the floating object. However, the flow rates during the rainy season and dry season fluctuate dramatically in this climate. Tim Burke mentioned in one of his emails that during the dry season the water got to be as low as about $\frac{1}{10}$ of the flow recorded during the rainy season.

The final survey of the Cascada site established maximum and minimum flood plain elevations. The land survey was acquired using standard transit-stadia methods as stated in the provided handouts and references. Based on time constraints, the survey loop was not closed, but arbitrary benchmarks were placed. The distance from Cascada Pequeña to the community was measured for wiring purposes. This was done using a GPS with a horizontal (elevation) accuracy rating of ± 40 feet. A GPS location of a benchmark was taken and photographed for future construction purposes.

Piriatí's water storage tank was located and examined for reference. This was done to obtain a flow rate and potential head for the Toma, which is the community's water intake. Through exploration and community input, it was determined that the inlet to the community's water system is located approximately 5 kilometers from the water storage tanks.

Alan Foster is a former Peace Corps volunteer who has worked with both the Emberá people and the adjacent Latino Community. He currently lives in a community that is located near the project site and has proven to be an invaluable resource. He supplied information that led to several alternative hydroelectric sites. A hike was led by a member of the Latino community and a member of the Emberá community in order to collect data at these sites. Four potential sites were located, and site data such as flow rates and change in elevation (head) were collected. Head was found using a measuring tape on small falls, a 50 foot rope tied to a rock was used for mid height (15 to 50 feet) falls, and GPS data was used for the largest falls. Flow rates were found using the float method as described earlier.

Two out of the five sites investigated proved to be feasible sites for hydroelectric generation. Unfortunately, accurate surveying data was difficult to obtain due to lack of time, resources, extreme trail conditions, and the fact that little was known about the falls and their locations prior to the exploration hike. Google Earth combined with collected GPS points has been used for the majority of mapping details.

Along with collecting technical data, more qualitative data about the community was collected. Random community surveys were conducted to create a general profile of the average community member. The parameters of the survey included questions on current average income, number of people living in each household, current contributions to the electrical system (if applicable), and wants or needs of a future electrical system (if applicable).

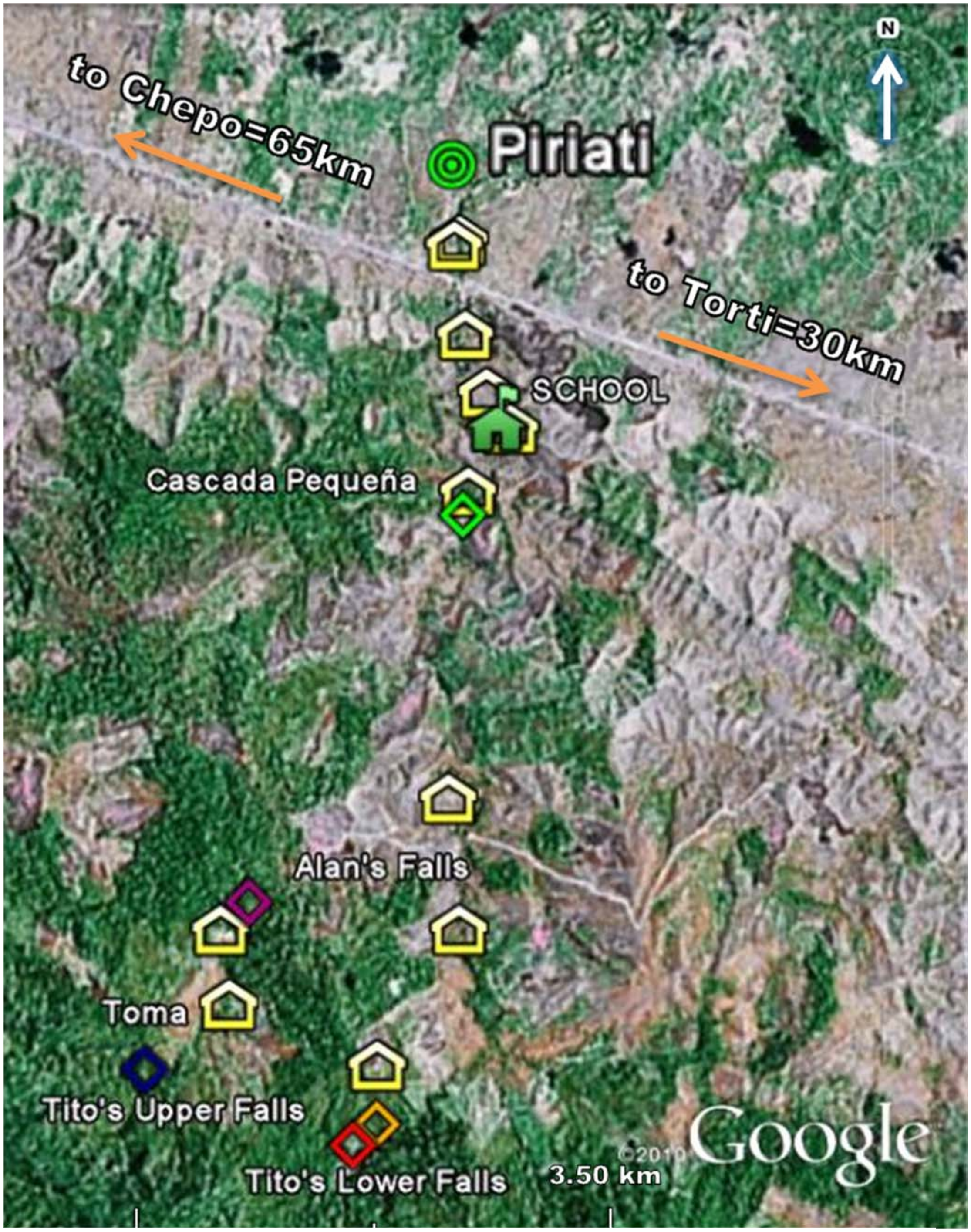
4.0 Alternatives Analysis

Five potential sites for a micro hydro-electric generator were identified while in the community. The sites included are the Cascada Pequeña, Alan's Falls, The Toma, Tito's Upper Falls, and Tito's Lower Falls. In addition to this, a potential site was suggested after the assessment trip took place. This potential site is Cascada Pequeña with a power canal. The following table is the critical information used in the alternatives analysis for all of the sites previously mentioned.

Table 1: Compiled Site Data

Waterfall Site	Transmission Distance (Km)	Potential Head (m)	Flow Rate (lps)	Potential Power (kW)
Cascada Pequeña	2.6	2.1	969	4.2
Cascada Pequeña w/ PC	1.1	9.1	309	7.4
Alan's Falls	5.5	22.9	149	9.9
Tito's Upper Falls	7.2	22.9	202	13.8
Tito's Lower Falls	7.0	24.4	202	14.7
The Toma	7.1	61.0	62	9.3

The following figure is a graphical representation of these sites. This site map includes the location of all the houses visited in Piriatí Arriba, indicated with yellow house as well as each potential waterfall site, labeled and indicated with multi-colored diamonds. The data used to create this map was collected using a personal Garmin GPS.



The

Figure 1: Site Map

feasibility of each site was based on the distance from the site to the community, potential head, potential power, and requests from the community members. From the above table it can be seen that Tito's Upper and Lower Falls have the greatest potential powers, but they are located furthest from the community. Alan's Falls is next in line for highest potential power and about midway between The Toma and the community. The Toma has a medium potential power and is located at approximately the same distance from the community as Tito's Falls. Lastly, Cascada Pequeña with a Power Canal and Cascada Pequeña provide the least potential power, but are the closest sites to the community. More information on these sites can be found in the sections below. For more graphical results see Appendix B. Also, flow rates were delineated through the use of GPS data and topographical maps via Google Earth. A watershed delineation map and a site map including all of the locations of the sites can be seen in Appendix D.

The following table, Table 2: Power to Distance Analysis, has been one of the primary tables used to determine the most efficient site. Cascada Pequeña w/ and Power Canal has the best power to distance ratio of 6.76.

Waterfall Site	Transmission Distance (Km)	Potential Power (kW)	Power/Distance
Cascada Pequeña	2.6	4.2	1.62
Cascada Pequeña w/ PC	1.1	7.4	6.76
Alan's Falls	5.5	9.9	1.80
Tito's Upper Falls	7.2	13.8	1.92
Tito's Lower Falls	7.0	14.7	2.10
The Toma	7.1	9.3	1.31

Table 2: Power to Distance Analysis

The numerical breakdown of all of these sites have been discussed, but other factors such as road conditions to the sites, land ownership, and costs have yet to be discussed. The next sections break down the individual sites using more than just the analytical information discussed in this section.

4.1 Cascada Pequeña

The Cascada Pequeña is located approximately 2.6 km from the community. Assuming no flood plain and no site modifications (i.e., the turbine may be placed immediately adjacent to the river), this site has a potential head of 2.1 meters, flow rate of 969 L/sec, and potential power of 4.2 kilowatts. The survey data used to determine potential head for this site can be seen in Appendix C.

The Cascada Pequeña was the team's focus of study due to the fact that a feasibility study had been written by Tim Burke concerning this location on June 17, 2010 (T. Burke 2009). This waterfall is the closest to both Piriatí and Piriatí Arriba; however, it also has the lowest potential head of all the sites— 2.1 meters from the top of the falls to the generator site. The elevations at this site were calculated using Transit-Stadia methods due to the fact that the height differential was so small. Although this waterfall has a small potential head, it has a considerable flow rate of 969 liters per second. This value was measured using the stream float method and was comparative to the value approximated in Tim Burke's feasibility study.

Using half of this site's flow, a potential power of 4.2 kilowatts was calculated. The estimated seven feet of head would place the generator in the river's floodplain and therefore would require the implementation of a hydraulic structure. In addition, the output is not capable of meeting the demands of the community. The community's current diesel generator yields 15 kilowatts when operating, so a generator system here would only about one-third the amount of power the community is used to. However, this site could be used as a partial system, possibly used to power specific buildings like the two schools and the medical facility. The greatest benefit of this site is its close proximity to the community at 2.6 kilometers.

4.2 Cascada Pequeña with Power Canal

An alternative design could be implemented at Cascada Pequeña. In Tim Burke's feasibility study (T. Burke 2009) it was suggested to dig a canal along a series of gently sloping contour lines. The canal would move water from above the falls at Cascada Pequeña to a site that had more potential head. The idea is to cut a canal at a slight slope following the topography of the land until an elevation change of 9.1 meters is achieved further downstream.

This alternative has the potential of generating 7.4 kilowatts of power using a diverted flow 227 liters per second. Although the magnitude of the work load seems unreasonably large, the people of Piriatí recently dug a longer canal over rougher terrain. The community dug a 9 kilometer aqueduct by hand in order to lay pipeline to bring water to Piriatí, as discussed in section 4.6. The labor was supplied by the Emberá community. Therefore, this option cannot be discounted because of the amount of labor it will require.

4.3 Alan's Falls

Alan's Falls is 5.5 kilometers from Piriatí and has a total head of 22.9 meters and an estimated flow rate of 149 liters per second. At 5.5 kilometers from the village, Alan's Falls has been selected as one of the primary alternatives, given the high flow rate and a potential power of 9.9 kilowatts.

This site is comprised of 5 successive waterfall drops that span a distance of approximately 244 meters. The water falls are 5.5 kilometers as the bird flies from the community. In spite of this, the power output to distance ratio for this site is the best in comparison to the other sites, except for the power canal at Cascada Pequeña. However, Alan's Falls may be cost prohibitive due to the cost of transmission cable and the site's distance from the community.

There are many benefits to using Alan's Falls as a site of electrical generation. For example, the inlet has a natural pool to collect water from. Also, the potential head is significant enough that only 85 liters per second of water is required to produce 9.9 kilowatts of power. Flooding of the turbine and generator house is not a concern at this site.

4.4 Tito's Upper Falls

Tito's Upper Falls is located 7.2 kilometers from the center of the village. Tito's Upper Falls are not ideal, mostly due to the site's distance from the community and the high cost of transmission lines. With a potential head of 22.9 meters and flow rate of 202 liters per second, the total power output is just less than 13.8 kilowatts, which is on the low side. One advantage of utilizing this site is the fact that there is a fair amount of clearing at this site, especially on the west side of the falls where there is pasture land. Due to this pre-existing clearance, it would be fairly easy to put up transmission poles with little risk of falling trees affecting the function of the transmission lines.

4.5 Tito's Lower Falls

Out of all the falls surveyed, the least is known about this site, and the least amount of time was spent here. This site has a potential head of 24.4 meters and flow rate of 202 liters per second. As the site is 7.0 kilometers away from the village, it is not ideal— though the power is slightly higher than the Tito's Upper Falls, about 14.7 kilowatts. An estimated flow rate and head were measured, but a potential generator housing site was not identified due to steep and rocky terrain.

4.6 The Toma

The Toma is the inlet of the community's water system. This site is 7.1 kilometers from the community and has an estimated flow rate of 62 liters per second. Since this site is not a waterfall, the head was estimated to be 61 meters (200 feet), which is the elevation change from the Toma to the break pressure tank further down the aqueduct. Therefore, the estimated potential power for this site is 9.3 kilowatts. The greatest benefit of using this site is that it is at the same location as the community's water inlet, and therefore could reduce the time required for maintenance since both inlet systems would be designed similarly. However, this location would also have a lot of head loss in the penstock because the potential head of 61 meters occurs over a significant distance. Therefore, the Toma's distance from the community and its lower potential power it has also been written off as a potential site.

4.7 Do Nothing

From information received from both Alan McDonald and Alan Foster, to do nothing is a very feasible option. The team was told that five years ago the Panamanian government signed contracts to begin construction of transmission lines from Tortí to Piriatí. However, no construction has yet begun, and no one knows when or if it will. Yet even if power lines are brought to Piriatí, the community of Piriatí Arriba will most likely not be connected because the houses are so spread out. So some sort of power generation system will still be needed in Piriatí Arriba.

5.0 Recommended Alternatives

From the six site options listed above, two have proven to be superior to the others. These sites are Alan's Falls, at a potential output of 9.9 kilowatts, and Cascada Pequeña with a power canal, at a potential output of 10.1 kilowatts. More time will be required in Piriatí to study both sites in order to determine the best option of generation for the community.

5.1 Alan's Falls

Although the power output to distance ratio for this site is the best in comparison to the other sites (except for Cascada Pequeña with a power canal), this site may be prohibitively far away from the community. The reason for this is that the cost of transmission lines is very high. The cabling would comprise about half of the total cost of the project. Therefore, a closer site would be more feasible. These falls are also in the middle of dense, steeply sloped jungle, and hanging cables could potentially be in danger of falling trees if the forest is not cleared properly.

The path that runs along Alan's falls is a cattle drive trail. This trail is mainly comprised of clay and silt. During the rainy season the trail is difficult to maneuver and may affect the pace of construction. Currently the project has been projected to take about 5 months to complete starting at the beginning of the dry season. However, if the project runs longer than anticipated this could be an issue.

Despite the challenges that may be faced with using this site, there are many positive aspects that should be considered. This site does not require an extreme amount of renovation for an intake to be fully submerged because water collects in a pool just upstream of the falls. Also, with some precaution, a penstock would be relatively easy to place and construct. The penstock will follow the topography, and on-site adjustments can be made for routing through or around challenging areas, such as valleys, dense jungle, or rock formations. There is not much concern when working in an area where there are waterfalls, because the excess water spills over one fall and on to the next pool. The biggest concern with flooding in this project is the extreme amount of damage flood waters could do to a foundation, turbine, and generator.

A site for the foundation, turbine, and generator house was not established. However, there could be a potential site past the bedrock bank on the east side or further down the river next to the small foot path. This site could be a realistic place to house all of the components without worry of flood waters.

5.2 Cascada Pequeña with Power Canal

Due to the late arrival of this suggestion, a complete design at this site was not feasible. Also, the preliminary design specifications of this site are based in Google Maps topography. Therefore the accuracy of this design is not adequate enough to provide final design information. However, many of the aspects of a hydroelectric system at this site are similar to the design aspects for Alan's falls.

As previously discussed, the proposed power canal is 1.7 kilometers (5740 feet) long and would be primarily hand dug. A suggested channel location can be seen below in Figure 2: Recommend Path for Canal and Penstock Location.

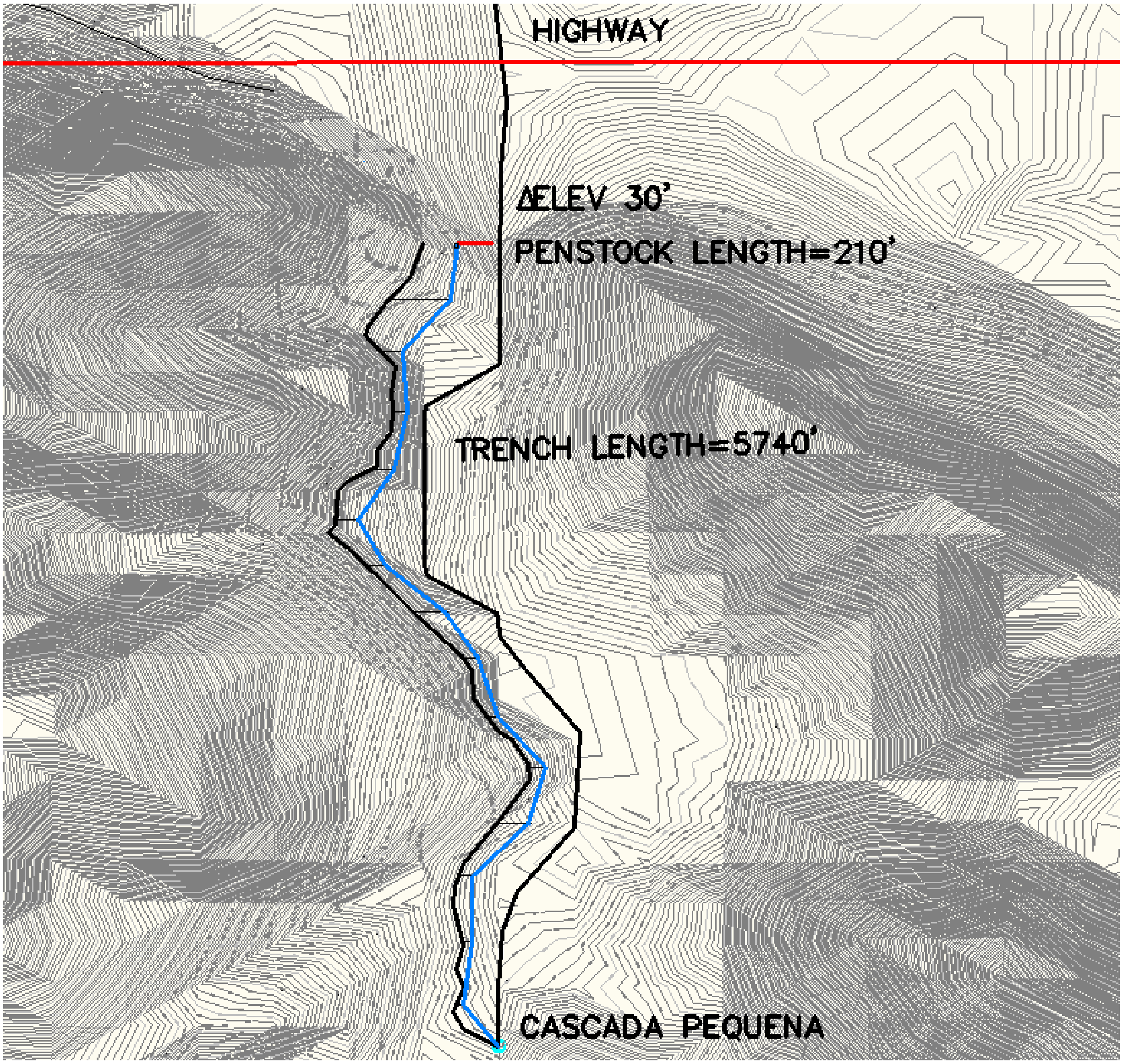


Figure 2: Recommend Path for Canal and Penstock Location

From the above figure, the bold black line on the left is a contour line at an elevation of 109.7 meters (360 feet). The bold blue line is a potential path for the power canal. This line drops down a two foot contour line; the contour lines are represented by the fine lines, about every 115.8 meters (380 feet). The bold fine lines that cross from the109.7 meters (360 feet) line to the blue power canal line represent the locations of this designated drop. The reason for this drop is to keep the water flowing downhill.

The short red line represents the recommended placement of the penstock. This line also represents a changed in elevation of 9.1 meters (30 feet). There for this site has a potential head of 9.1 meters (30 feet). Lastly, the bold black line on the right represents the river and the long red line that runs a crossed the top represents the road.

This design would require blasting sections of rock near Cascada Pequeña and possibly using wooden flumes to carry water over small gorges. In order to settle out sediment suspended in the water from the canal, a settling basin has been designed at the end of the canal, before water enters the penstock.

Potential power, slope calculations, canal specifications, settling basin design, AutoCAD© site drawings and other details concerning this option can be seen in Appendix G: Cascada Pequeña with Power Canal.

6.0 Data Analysis and Design Specifications

The primary in-country focus was collect data to be used in designing a system for Cascada Pequeña. Other potential electrical generation sites were identified while in country. It is noted that surveying equipment was not able to be taken to the Alan's Falls site at the time of travel, and therefore less data exists for this site than Cascada Pequeña at this time.

An electrical hydropower system is dependent on the functionality of several important subsystems. The success of all of these systems, as well as their ability to work together, will provide an output of 120 Volts Alternating Current (AC) at a homeowner level. These systems will be discussed as follows:

1. The river and the water intake site
2. The generator shelter (which includes the turbine and generator)
3. The transmission system
4. The distribution system (including distribution lines and house connections)

Each section will be discussed in detail in the appropriate sections below.

6.1 Inlet

The inlet and penstock designs are similar to the design implemented at Agua Fría (see Tim Burke's As Built Documents on the digital appendix provided on the compact disc). The inlet is a simple pipe with a screen/wire mesh cover cased in a rock cage; see Figure 4: Inlet Design for details.

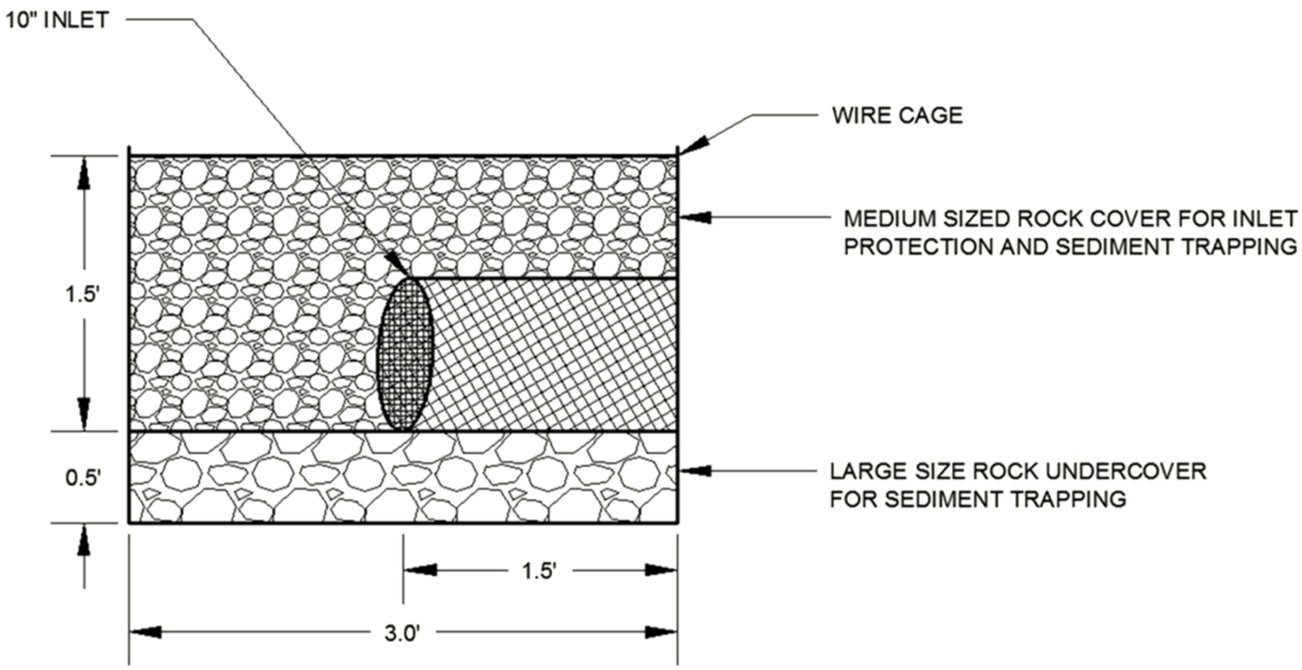


Figure 3: Inlet Details-Profile View

The inlet will be set up on a bed of rocks, at least 6 inches in depth, and then covered in rocks. This will keep the inlet secure and water reasonably clear of sediment and other debris. See Appendix F: Inlet Details for more information. This inlet design will be used regardless of the inlet site location.

A water diversion structure may be needed at Alan's Falls due to a potential low flow rate in the dry season. The hydraulic structure will be made out of large boulders from the river to direct the water into the intake while not damming the river.

6.2 Penstock Design

The penstock at Alan's falls will be connected to the intake and will run along the west bank of the river. The penstock will be made out of a 10" PVC pipe. The pipe will be buried on gradual side slope and will be supported with steel rebar when crossing rock outcroppings. Thrust blocks should be constructed out of concrete or large rocks should be used where ever there is a sharp bend in the penstock as described in the journal article, *Pipeline: Hydro-Electric Penstock Design* (Ostermeier 2008). From calculations, total force in this pipeline should never exceed 224.1 kPa (32.5 psi), so thrust blocks are precautionary. For pressure calculations see Appendix B: Pressure Calculations. It is essential to have as few sharp bends as possible in the penstock to reduce energy losses.

There is one location at Alan's Falls that the penstock will need to cross a distance of about 50 meters that has very little change in elevation. At this point there may be one sharp bend if the penstock is not suspended. If the penstock is suspended over this valley, keeping the pipe at a more consistent slope, a significant amount of energy will be conserved and the risk of clogging due to sediment deposits will be minimized. The community already has experience in constructing supports for pipelines, as they constructed their aqueduct. This technology of simple timber "A" frames will be used if deemed necessary. The penstock will need to be 230 meters long to carry the water to a suitable generator location. The alternative site at Cascada Pequeña would require rock blasting in order to divert water through a pipe and into a constructed channel. The location and specifications of the inlet, trench, settling basin, and penstock for Cascada Pequeña are described further in Appendix G.

At Cascada Pequeña with a power canal, the penstock been designed to be a 10 inch diameter PVC pipe that would run downhill at a slope of about 14% (see Appendix G for details on the penstock geometry). The penstock length has been design to be approximately 64 meters (220 feet) The outlet nozzle has the same design as the one for Alan's falls.

6.3 Outlet Design

Typically when designing a nozzle, the circular cross-sectional area of a pipe is reduced into a smaller area to concentrate the water onto the turbine. The unique design of the cross flow turbine (discussed in section 6.8) requires a rectangular jet of water rather than a circular one. The usual nozzle used on the cross flow turbine is an adjustable distributor so that the flow can be manually regulated. Manual regulation is not feasible due to the great distance between the community and the site, as well as the fact that the complexity of the design will prohibit it from being locally fabricated.

To solve these problems, a simpler nozzle was designed. It can be seen in Appendix Q: Mechanical Drawings and Specifications for Crossflow Turbine & Nozzle. This new nozzle can be constructed simply by cutting the shapes out of sheet steel and welding them together. The nozzle will then be welded to a short 10 inch steel pipe that will be threaded and screw into the penstock. This nozzle will be less efficient than the traditional adjustable nozzle, or even a static nozzle without any flat edges, but the positives of a simple design and low cost greatly outweigh the negatives in this instance. A three dimensional model of the nozzle can be seen below.

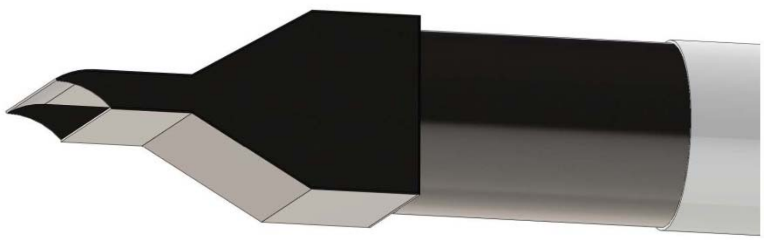


Figure 4: Nozzle Model

6.4 Turbine and Generator Shelter & Foundation Specifications

The turbine/generator system will need to be sheltered for a number of reasons. All that is needed is a small shed to keep out the elements, with possibly a fence. The fence is unnecessary if the shed is strong and can be locked, but the system must be isolated. The turbine will have no other coverings, and it will have very sharp, fast moving parts.

In addition to safety ,a simple guard will need to be placed either over the turbine or between the turbine and the generator to keep the generator dry.

The foundation for the turbine and generator will be constructed at the bottom of Alan's Falls. Since this area is heavily wooded and littered with boulders, a small section will need to be cleared and leveled. An appropriate site will be located out of the flood plain and preferably on the west side of the river. The foundation will be a two meter by three meter reinforced concrete pad on which the turbine and generator will be secured.

Water that is focused into the turbine by the nozzle must also be diverted back into the river. This could be done by constructing a shallow open flume starting at the foundation and running back into the stream. This flume would maintain the river's water quality since erosion would be controlled. By controlling erosion the issue of undermining will also be addressed. If the alternative site of Cascada Pequeña is selected, the construction of the foundation would remain the same but the foundation would be relocated to just south of the bridge. At this site flooding will be more of an issue since the topography is much more gradual, and therefore the siting of the foundation will require careful consideration.

6.5 Turbine Design

Initially an impulse type turbine was chosen— specifically a Turgo wheel. Unfortunately, there is limited information available for Turgo wheels, and the shape is too complicated for prototyping; this makes designing for maximum efficiency very difficult. A cross flow turbine will be used instead. Cross flow turbines are technically in the impulse turbine family, but they operate efficiently in the range between impulse turbines and reaction turbines. The water is ejected through a nozzle, and the potential energy is converted to kinetic energy. This jet of water impacts the blades and causes the turbine to spin. The difference between the cross flow and impulse simple: the water flows through the cross flow wheel and impacts the blades twice, whereas the water in an impulse turbine only impacts the outside wheel once and discharges. A diagram of the water path through the turbine can be found below in Figure 5.

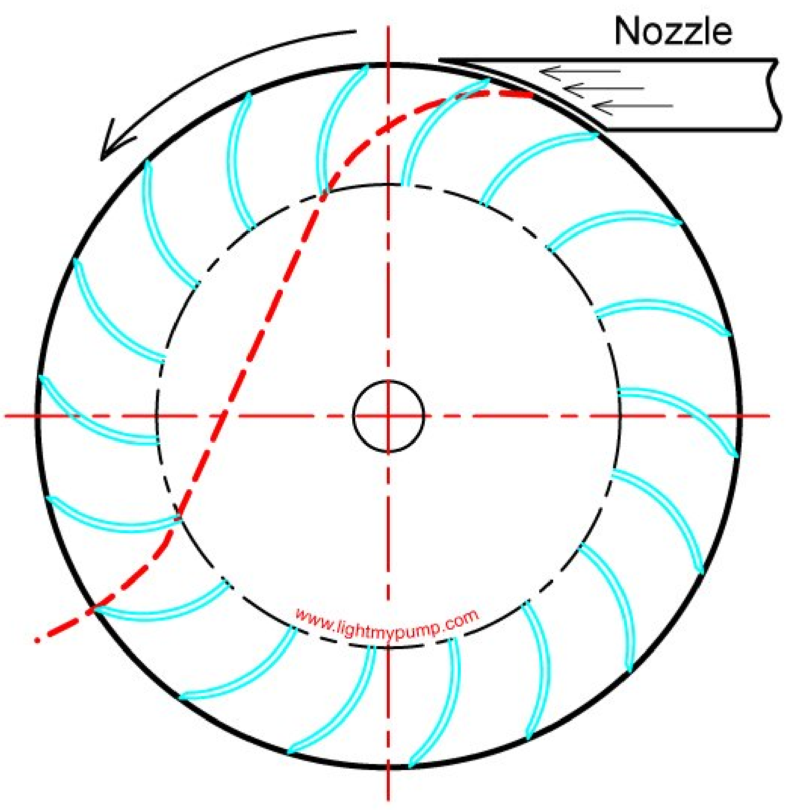


Figure 5: Path of Water through Cross-Flow Turbine

The first time the water hits the blade, the water is moving from the outside of the turbine to the inside. The turbine absorbs about 75% of the total absorbed energy from the water, which is approximately 49% of total energy. The second time the water hits the blade, the water is moving from the inside to the outside of the turbine. During this process the turbine absorbs the remaining 25%, which is approximately 16% of total energy (Light). These numbers are based on an estimated turbine efficiency of 65%. One major benefit to this design is it is somewhat foolproof. If the wheel is not sized perfectly and it does not absorb as much energy as it should on the first pass, the water will have more energy whilst traveling through the wheel and it will absorb more energy on the second pass. Another advantage is the design is relatively simple. The blades have a uniform radius so they can be cut from a pipe. This means the turbine can be easily and cheaply fabricated in country.

A scaled down prototype wheel was constructed out of CDs, aluminum soda cans, hot glue, and epoxy. An image of this prototype is attached in Appendix P: Turbine Prototype. The main purpose of this scale model was to determine the necessary size of the final turbine; however, after its completion, a better, more accurate method was discovered. A simple equation can be used to discover a value for the width of the turbine times the diameter of the turbine. The equation is:

$$L * D = 2.627 * \frac{Q}{\sqrt{H}}$$

where L is the width of the turbine in meters, D is the diameter in meters, Q is the flow rate in m^3/sec, and H is the head in meters (Cross-Flow Water Turbine: A Design Manual). Once this product was found, an Excel® spreadsheet by Max Enfield, Technical Director of Planetary Power, was used to find the optimum ratio of width to diameter. The spreadsheet would calculate the power output based on head, flow, diameter, and width, so a trial and error system was used until the optimum ratio was found. Max also said that the diameter to width ratio should lie within the range 1:0.7 to 1:3, but fortunately the optimum efficiency calculated was right in the middle of this range. The reasoning for this range is that if these values are exceeded, vibrations or flexing of the blades can occur. The final specifications found were a diameter of 200mm and a width of 275 mm, and shown in Appendix Q: Mechanical Drawings and Specifications for Crossflow Turbine & Nozzle.

Once the outer diameter is determined, there are a series of calculations to spec the rest of the turbine. To find the inner diameter, the equation: $D_{outer}/D_{inner} = 0.66$, is used. The inner diameter represents the point at which the blades stop and the wheel opens up to allow the cross flow and this value was calculated to be 132 mm. The radius of the blade is given by the equation: R = 0.326 * (D_{outer}/2). The radius was calculated to be 32.6 mm. 18 blades are placed evenly along the periphery of the outer disc. This placement requires 20° of separation between the blades. All of these specifications are detailed in Appendix Q: Mechanical Drawings and Specifications for Crossflow Turbine & Nozzle.

A simple rack was also designed to hold the turbine off the ground. The turbine needs to be elevated so the ejected water does not interfere with the rotation of the blades. This rack consists of two triangles made up of square pipe, a small plate with a hole that the shaft of the turbine is welded to on each side of the rack, and bolt plates so that the rack can be mounted to the foundation. The specifications for the rack are located in Appendix Q: Mechanical Drawings and Specifications for Crossflow Turbine & Nozzle.

A 2” polyurethane belt will be used to connect the turbine to the generator. Polyurethane was selected due to its ability to fit the small radius of the belt runner on the generator. However, if rubber were used, the belt would not wear away as quickly (McMaster-Carr). A grooved roller bearing with an inner diameter of 30mm and an outer diameter of 40mm was selected as the best bearing to use for the turbine (McMaster-Carr). However, if a similar bearing is more easily obtainable in country it can be used as long as the dependent turbine dimensions are adjusted accordingly.

All of the previously mentioned components were modeled in 3-D with Solidworks©. These 3-D models were used to create 2-D drafting views in Solidworks© as well. The purpose of the 3-D model is to give a strong visual reference of the turbine, while the 2-D drafting views will be used for fabrication. The 3-D model can be seen in the figure below and all of the 2-D drawings are located in Appendix Q: Mechanical Drawings and Specifications for Crossflow Turbine & Nozzle.

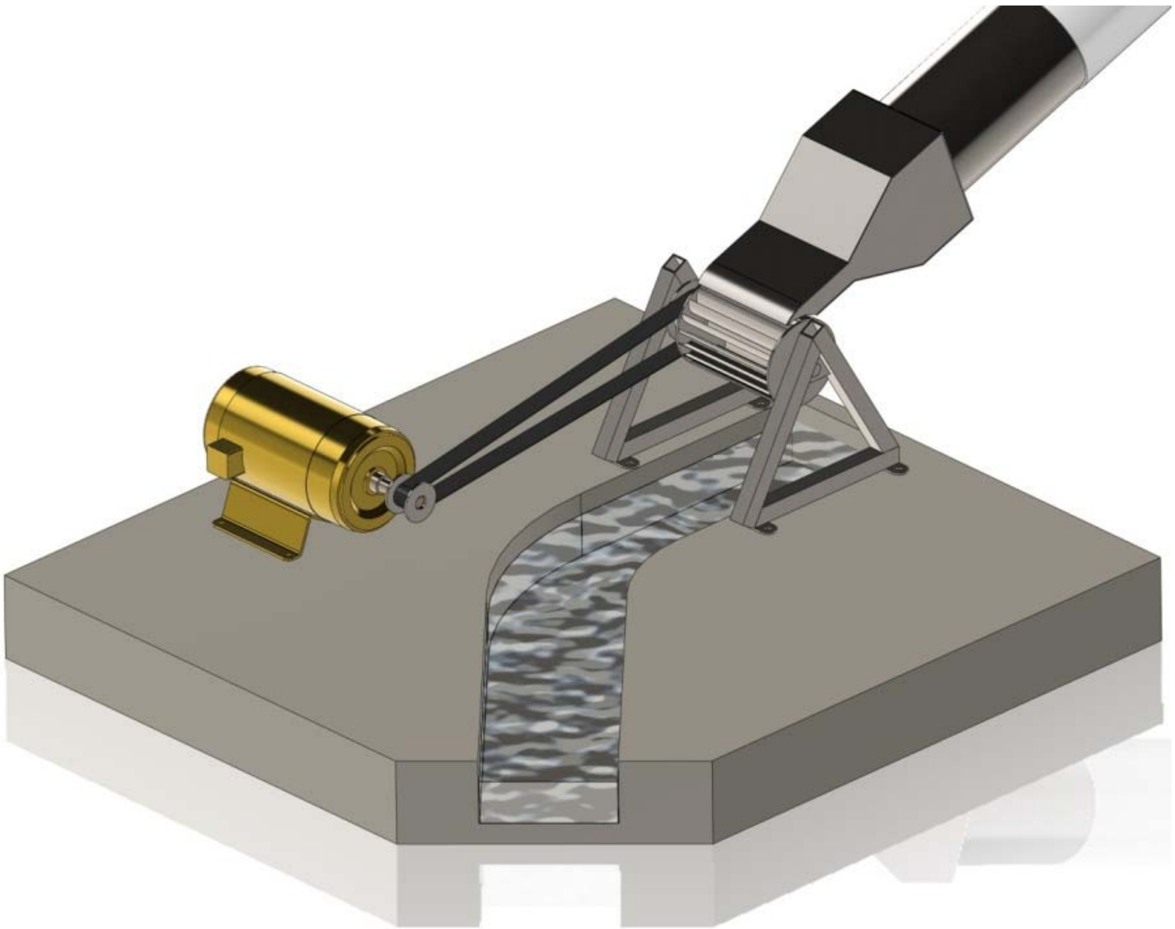


Figure 6: Complete Turbine Assembly

6.6 Generator Specifications

Generators come in a variety of types. One of the main differences in generator types has to do with the rotor, which is the part of the generator that is connected to the turbine. The rotor can either be composed of a strong permanent magnet, or it can be an un-magnetized material wound with conductive coils.

Generators also come in synchronous and asynchronous (induction) models. In a synchronous generator, the output voltage and frequency is directly tied to the rotor position. This can be achieved by either a permanent magnet rotor or a dc-conducting slip ring, which produces the magnetic field necessary to induce an output current.

Asynchronous generators require a current to be supplied to the rotor conductors as they spin. The magnetic field produced by the rotor induces a current in the stator windings, causing a rotating magnetic field in the stator. Unlike the synchronous generator, the asynchronous generator's output is not directly tied to the rotor's position. The speed at which the rotor must spin to induce a current is slightly higher than the output's rotating magnetic field. If the two magnetic fields were synchronized, they would not be moving relative to each other, and no current would be induced in the stator. The ratio of the stator speed relative to the synchronous speed is called slip (Wikipedia 2011).

The current design for the generator will be a three-phase (asynchronous) induction motor of an equivalent power rating (15-20 horsepower). There are a number of reasons why induction motors are a better fit than a pre-fabricated generator (Smith 1994):

- Induction motors are globally produced and distributed; therefore, one with the specified power rating for this project would be easy to obtain. A generator of the same power output (like the one connected to the diesel generator in the village) is much harder to find.
- Induction motors are intended for constant use; hence, they have a designed robustness to them. Analogous generators are intended for intermittent use so the life expectancy is not nearly as high.
- Induction motors are inexpensive as compared to a similar power synchronous generator. An induction motor (with fitted excitation capacitors) generally costs about half as much for the same power output.

The current design calls for a 15 horsepower motor (product number JMM2513T) produced by Baldor. The specifications for this particular motor can be found in Appendix K: Motor Specifications (Baldor Electric Company 2011). Also, Appendix K: Motor Drawings shows a technical drawing of this motor, which will be useful when constructing the mounts for the turbine belt. From the information supplied by Tim Burke, a small Hydro-electric company in Nicaragua, ATDER-BL, supplied the excitation capacitors as well as motor winding fixes (to output the correct voltage). For reference, a sample calculation shows how the values for the excitation capacitors are obtained and is given in Appendix L: Capacitor Calculations.

6.7 Control of the Electrical Load

An essential part of the generator is the load controller. All power systems must be balanced to maintain proper operation. Balancing involves using all power generated by a power supply; all the power must either be consumed by the village, or used elsewhere. There a few different scenarios in which a system would find itself unbalanced. The first scenario is when there is more power being generated than being consumed. When this happens, the generator has a tendency to speed up as it is not being retarded by a large load. This is similar to the difference between coasting down the hill with the car in gear versus coasting down the hill while the car is in neutral. In neutral, there is no limiting force on the wheels and it is free to accumulate as much speed as it has potential energy. The second scenario is the opposite of the first: there is more power being consumed (or demanded) than there is power being generated. When this happens, the tendency of the generator is to slow down, as more current is trying to be pulled from it. Back to the car example, the same amount of gas that it takes to rev the engine at a high speed in neutral will produce a much slower engine speed when it is in gear. Generator speed is a function of how much load is attached to it.

Both an underload and overload of the generator will produce a variation in frequency. This is desired to be minimal, keeping frequency as close to 60 Hz as possible. When the system is balanced, as previously mentioned, the frequency will remain steady. The solution to active load management is the load controller, which monitors the system to make sure all the power produced by the generator is getting consumed either by the village, or externally attached loads called ballast loads. This load can take several different forms, but are usually light bulbs or heating elements.

The electronic load controller works by monitoring the frequency of the generator. It is essentially a feedback controller, meaning that if it detects any changes in frequency, it will make a correction to the load by either attaching a ballast load, removing a ballast load or, in rare circumstances, detaching a user load that is on low priority. Electronic load controllers are available in a variety of types and utilize many different kinds of schemes to accomplish its purpose. This section will focus on just one topology created by electrical hobbyist Manfred Mornhinweg. For reference, a schematic of this circuit has been enclosed in Appendix L: Electronic Load Controller (Mornhinweg 2009).

The PIC16F628 is a small microcontroller that can be programmed for various functions (Mornhinweg 2009). In this case, the programming is done to track the zero crossing of the generator frequency and compare it with the 60 Hz frequency produced by its onboard quartz crystal. When there is an imbalance, the microcontroller will send out a pulse to correct it. This pulse triggers the necessary channel on which the bipolar junction transistor lies, which in turn amplifies the signal and triggers the TRIAC.

The TRIAC (short for triode for alternating current) is essentially a switch. It has three terminals: A1, A2, and Gate. When a current applied to the gate terminal is above the threshold limit, the TRIAC will act as a closed switch and begin conducting (Kuphaldt 2000). TRIACs are used because of their large capacity for handling current. The TRIACs shown in the schematic are rated at 16 A per piece, which is enough to support around 3.5 kW per channel. As shown in the schematic, the TRIACS are connected to the high side of the circuit (the 220V side), while the rest of the control circuit is on the low side of the circuit (the 9V side). When the TRIAC is opened up, current is allowed to flow through the ballast load, which keeps the power balanced.

6.8 Transmission Specifications

Special considerations have been proposed to compensate for the transmission of electricity over several kilometers of rough jungle terrain. First, an effective way to run electrical cables through the jungle was devised. It was determined that it would be better to run overhead cables as opposed to underground cables, mostly for maintenance reasons. If a fault occurs along the transmission line, it is much easier to find with overhead cable rather than buried cables.

A method for hanging the transmission cables on the poles also needed to be considered. The electrical system implemented in Agua Fría utilized live trees as electrical poles. A thinner gauged tie-wire was wrapped around the transmission cabling and stapled to trees with thicker fencing staples; in the event of a tree falling onto the transmission cabling, the tie-wire would break, and save the significantly more expensive transmission wire from becoming permanently damaged (T. Burke 2009).

The third consideration is the transmission voltage. Transmission lines have a certain gauge, determined by the cross-sectional area of the cable. Bigger gauges (the largest specified gauge being 0000, which has a diameter of .46”) can support higher currents. Each gauge of wire (also dependent on the material used) has a specified resistance per unit length. Given that $P = I^2R$, where I is current in amps and R is resistance in ohms, the higher the current in a transmission line, the more power will be lost due to resistance. This decreases the system’s overall efficiency.

One solution to this problem can be achieved by examining another formula for power: $P = VI$, where V is voltage in volts. If the output power of the system is fixed, then a change in either voltage or current will inversely affect the other. Therefore, as voltage increases, current decreases. For electric power transmission over long distances, high voltages are ideal to cut down on the loss associated with line resistance.

This transmission system was originally going to be designed for a higher voltage transmission – somewhere in excess of 2,000 volts. However, after calculating losses, distances, and cost per kilometer of larger gauged transmission cabling, it was found that 600 volts would be an appropriate transmission voltage from the step-up transformer at Alan's falls to the community, and that 480 volts could be used as a reasonable step-up voltage from Cascada Pequeña because of the minimized transmission distance.

By using 600 volt or 480 volt transmission voltages at each site, respectively, the cabling size can be reduced, and therefore the overall cost of the system is reduced.

Transmission lines come in all different shapes and configurations. There are two main ways to measure the diameter of these wires: the American Wire Gauge system and the Circular Mil System. The American Wire Gauge system is used for small gauges of wire, ranging from AWG 40 (.0021 *inch* diameter) up to AWG 0000 (.46 inch diameter). From there, the circular mil system takes over, starting at 250 kilo circular mils. For reference, 1 mil is 1/1000th of an inch. Circular mils measure the cross sectional area in a different way than using a square area system. For instance, the area of a 100 mil circle (.1 inch diameter) would simply be 100^2 or 10,000 circular mils. For this project, however, the wire gauges will not reach above AWG 0 for cost purposes. Appendix L: AAC Table shows a table of All-Aluminum Conductors with various useful values such as strand number, conductor diameter, dc and ac resistance, and weight per unit length, among other values (Southwire Company 2009).

It is important to understand how transmission lines will affect the output power and the voltage. A more detailed look at the power loss calculations can be seen in Appendix L: Voltage Drop Calculations. The larger the wire, the less power loss there will be, and also the less voltage drop there will be along the way. There exists a delicate balance between cost and power loss. Ideally, the largest gauge of wire possible would be used for the transmission of this system to minimize the undesirable voltage drop that occurs with highly resistive lines. Unfortunately, as the gauge of wire increases, so does the price. The cost for a km of aluminum AWG 0 wire line is around $1500. Considering that AWG 0 wire is around $200 per kilometer more than AWG 2 wire for about 25% more diameter, the cost quickly increases for larger gauge of wire.

Inherent to transmission lines is the concept of self-inductance and equivalent capacitance. Inductance occurs in a line by itself due to the magnetic field produced by the alternating current, but more significantly when in the presence of another loop of wire, or the neutral wire in this case. Similarly, capacitance occurs between the two lines because of the unequal electric fields in the lines caused by the different voltage levels. Apparent power is made up of both real (resistive) and reactive (inductive/capacitive). The summation of these two vectors results in the apparent power of a system. Inductance adds reactive power to a system, while capacitance removes reactive power. In this system, there is an inherent inductance due to the motor. Line inductance increases reactive power in the circuit, which in turn lowers the power factor (or the cosine of the angle between real and reactive power). As was shown in the capacitor calculation, a lower power factor will yield a lower real power for the same generator. Therefore, it is helpful to analyze the inductance and capacitance of the lines to help estimate additional real power loss in the system. Appendix L: Line Calculations shows a sample calculation of a single phase circuit using AWG 0 wire with 2 feet of spacing between the hot and neutral lines (Glover, Sarma and Overbye 2008)

Transmission pole placement should take into consideration geographical constraints such as height of placement (either on top of a hill or very low in a floodplain). In the case of Piriatí, it will be important to try to avoid ravines or flood plains in placing transmission lines for Alan's Falls. Significant drops or increases in the grade of the land should be avoided as well. A change in height should be less than five feet between two poles spaced less than 150 feet apart and ten feet for poles spaced less than 300 feet apart. This avoids wasting lengths of wire, as well as any excess straining issues that may occur with an imbalanced level between two points on the electrical wire. Excess strain on the tie-wire (as proposed by Tim Burke (T. Burke, As-Built Documentation 2010)) may cause breaks or a weakening of the tension wires when trying to support the electrical wires through the distance of the system.

When implementing the tie-wire system within the transmission system, it is important to note that the transmission cables should be as level as possible, both with the ground and each other. Keeping a specific height between the transmission cables and the ground for clearance is less important, especially in the densely forested areas near the river. As the wires are insulated, there is less concern about animals, people, or other objects needing to cross under the wires. Near known high traffic areas, ground clearance must be sufficient. It is likely that the wires will end up being placed at variable heights on each pole to maintain the stabilization of the wire, and this is mostly based on changes in geography.

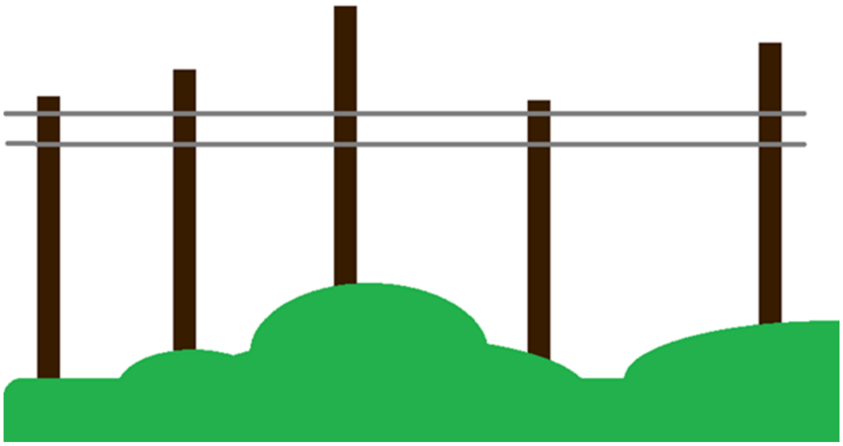


Figure 7: Transmission Wiring

Figure 17 is a diagram illustrating the importance of maintaining parallel and level cables along the distance of the transmission system and utility poles. It may be necessary to place cables at different heights along the utility pole to maintain the stability of the cables.

6.9 Distribution Specifications

Transmission lines coming from Alan's Falls will still be at 600 Volts as the cables enter the community. Each home will need to have a stepped down voltage of 120 volts to match Panamanian electrical standards. A step-down transformer of ratio 600:120 volts can be used to achieve household voltage supply. It is known that potentially up to 3 households can receive this step-down voltage from a single transformer if wired correctly before a "sag effect" will occur within the distribution. Due to this, individual step-down transformers should be used for every house wiring into the electrical system.

The existing distribution system within the community that is wired for the diesel generator cannot be reused due to the specific complex power and phase specifications of the diesel generator. Wiring will remain separate to avoid confusion, hazardous overloading of the system, or any other misuses of the two separate systems.

Generally, the difference between the transmission system and the distribution system is seen at the point of the step-down transformer that takes the higher voltage lines down to a lower and safer voltage for areas of population. However, it should be noted that insulated wire is being utilized at 600 volts, and the step-down transformation will happen at the home level. Therefore, the distribution system would only technically be viewed as an individual home circuit.

For generalization purposes, we will refer to the distribution system as the section of electrical wires that exists from a point of clearance on the south side of the main road bisecting the river and the communities to the last household being wired in the northernmost area of the community.

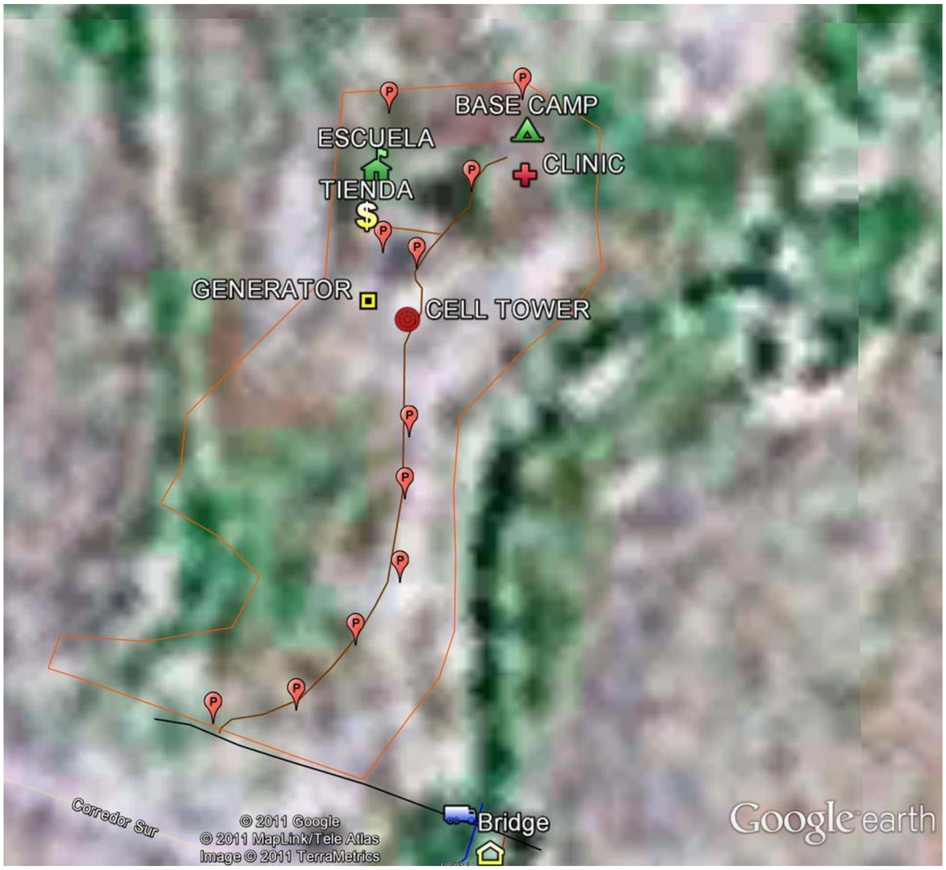


Figure 8: Map of the Distribution System

This map represents the distribution section of the electrical system. The highway is located at the “bridge” marker near the bottom of the map. Other labeled symbols represent major landmarks within the community.

The specifications for pole placement, wiring, and circuitry for traditional or standard distribution systems are still applicable to the community as a whole, and it is important to define these parameters in terms of construction and education.

There are several important considerations that should be taken into account by workers as they select the placement of the poles and wiring for distribution system. The overview provided in this section largely follows the specifications of Peace Corps manual on rural electrification, by Volunteers in Technical Assistance, Inc. , 1969.

Any poles that are placed near the main road that runs between the community and the river will need to be approved by the local government. They will have to meet specifications and requirements for transmission lines in Panama. These considerations are very important, because the community may be fined for construction that is too close to the road or that does not meet height specifications for road traffic. Specific construction information with the most appropriate local government office will need to be checked prior to project start.

Any constructed lines should run, as much as possible, through areas that have been cleared. For example, the main road that runs through the community will provide clearance around the distribution lines as well as easy access for maintenance and testing. Use of this road will also be beneficial in that it is the shortest access route to a majority of the houses within the community. However, for houses that are not on the main access road of the community, it is important to calculate and implement the shortest possible routes for pole placement. This, obviously, reduces costs by minimizing construction, poles needed, and wiring needed.

As with the placement of the transmission line poles, the poles utilized within the community need to be relatively evenly spaced (Volunteers in Technical Assistance, Inc. (VITA) 1969). Poles utilized within the community should be much more accurate in available ground clearance (distance from the ground to the lowest electrical wire) than the transmission system that runs through the forested area. The reason for this is to try to prevent injury or accidents with the lines. For this reason it is proposed that the distribution system use poles that are a minimum of 15 feet high. Two feet of the pole would be buried and stabilized, and two feet of spacing would be utilized between the two electrical wires to allow for sagging and placement of tension wiring. With this, approximately 20 feet of ground clearance (with a twenty-five foot pole, as an example) would be available underneath lines, which would be acceptable for vehicle transportation, animals, and foot traffic.

6.10 Metering System Specifications

Power consumption metering of individual households will be done through the community's energy committee that is already in place for the diesel generator system. Metering is an important aspect, as the system cannot be overdrawn at peak load times. Modeling the metering system used at Agua Fría, an amp fuse system will be used. An amp fuse is placed into the household circuit and will break the circuit if more amperage is drawn from the distribution lines than what the amp fuse is rated for. Using this idea, it is going to be suggested that the committee try to implement variable monthly costs based on the amp fuse rating that is purchased to regulate each home. For instance, if a family home only wants basic lighting, a 0.5 amp fuse can be purchased and used in conjunction with compact fluorescent energy efficient light bulbs (up to 60 W of usable power with a 0.5 amp rating) for a small monthly price. In contrast, a family that wishes to use a television, lighting, and other items that may draw more power could pay a larger monthly cost to purchase up to a 4 amp fuse, where 4 amps (which would supply 480 Watts of power) is the maximum cap per household based on the overall estimated output of the system at Alan's falls.

A sample wiring diagram to model how the metering system will be applied can be seen in Appendix I.

6.11 Community Education Efforts

Implementation of a hydropower system within the community of Piriatí brings a need for educative materials for community members. These may come in the form of pamphlets, open forums, community tutorials, and house visits. As only about half of the community members are currently connected to the diesel generator grid, and no families are currently running continuous power off of personal generators, it is extremely important to teach families about using power, especially when it is available 24 hours a day. Topics of discussion should include:

1. Ground wiring (at the home level)
2. Design and implementation of proper and safe house wiring
3. Understanding motor-powered equipment (differences in wiring and power needs)
4. Understanding and calculating loads
5. Safety
6. Medical Treatment (in conjunction with safety, in terms of electrical injury)
7. Establishment of a publicly known "point - of - contact" within the community that will service the system and the needs of individual homes

These topics are covered to a great extent within the Peace Corps Rural Electrification manual (1969). It is highly recommended that these materials be included and utilized during educational programs within the community (Volunteers in Technical Assistance, Inc. (VITA) 1969).

While community surveys were being conducted, several households gave permission for photographical documentation of their current home wiring systems an image of this is included in Appendix A. When the original electrification system was installed, each home that was connected to the system was allowed one outlet.

Figure 9: Sample of Current Electrical Wiring Within Homes

As seen in the figure above, an electrical power strip is plugged into one of the two original outlets. It is not actually being utilized for anything, but it will still draw power while electricity is running. The other original outlet is utilizing multiple extension cords connected together that are wiring all other electrical equipment in the house together in a series circuit. It is apparent that educational materials were not properly implemented or passed down within the community with the addition of the diesel generator system, and governmental assistance for house wiring was minimal, at best. Due to this documented concern, it is recommended that educational materials and demonstrations be mandatory requirements for, at minimum, the head of every household wishing to connect into a new system. This will not only prevent misuse of the system and reduce safety concerns, but it will also help to make community members more aware of power consumption and conservation.

7.0 Cost Estimate

The Cost Analysis was broken up into two main sections. The first section is the electrical equipment section, which contains the majority of the cost for this project. Items in this section include the motor, power electronics, transmission lines, metering devices, and wiring for houses. The second section is a breakdown of additional materials needed for the construction of the generator shelter, the penstock, the turbine, and the transmission line-to-pole tie system. Costs were estimated from Tim Burke's cost documentation from the Agua Fría system, though not all the costs could be obtained. The report included the transmission wire, the motor, the turbine, the transformers, etc., but did not include some of the various electronics needed for this project. Certain equipment such as fuses and switches, the ground fault interrupter, main disconnect breaker, transmission poles, concrete materials, and various other small materials were not given in the report and thus had to be estimated using other means.

As there are a few large industrial suppliers in Panama City, some costs were estimated using corporate websites. One such company, Grainger, has a very comprehensive online catalog with items ranging from motors and electrical equipment to PVC piping and tubes. A link for the Grainger website can be found in Appendix N: Cost Estimate. The prices on the site were used to estimate the cost for the project. Some materials, however, could not be found on websites for companies in Panama, and therefore had to be estimated from North American costs from various websites. Such items included electrical components like fuses and breaker switches, tools and concrete materials, as well as the large 10" PVC that the penstock is designed with.

Even still, a few materials were not found at all. The transmission poles for example, were quite elusive, and it can be inferred that costs and availability vary with location. From Tim Burke's as-built documentation, a large number of 12' poles were donated to the village. Tracking down information on these types of materials has proven to be a difficult task. These costs should be obtained from the people in the community of Piriatí. Additionally, a small part of the budget was reserved for an electrical consultant, a specialist to come out to provide the technical service of wiring up the generator housing and electronics, as well as supervising the hanging of transmission lines and the installation of home distribution systems.

The most expensive material cost associated with this project is the power lines. With the transmission lines, the in-village distribution lines and the home-wiring lines, the cost for these components is a little more than half the projected cost, $26,132. There is really no way to get around this cost, save for moving to a closer site to reduce the amount of 0 gauge wire needed, which costs about $1,500 per km (T. Burke, Cost Estimate 2010).

Broken up into six main components, the cost for each subsection is as follows: The electrical section has a projected cost of $46,300. The concrete, which includes the concrete base of the turbine-generator unit, is the lowest cost material at $240. The penstock boasts a sizable $3,600 because the cost for large-diameter PVC pipe is so high in price. The turbine has a projected cost of $340, with the most expensive item being the stainless steel needed for construction. The transmission materials, which include the poles, tie wire, and fencing staples might be a bit skewed at $120 as the cost for utility poles was not obtained. However, the option of hanging the insulated lines on live trees is an option. Finally, the technical personnel segment includes the cost of an electrical professional to oversee all the generator hook-ups, the transmission lines, and the home connections, was estimated at $1,600. This yields a projected total of $52,200 for all the materials, equipment, and labor for this project. The breakdown of costs by category can be seen below in Table 3: Cost Breakdown by Category, or in Appendix M: Cost Estimate for itemized costs.

Table 3: Cost Breakdown by Category

Cost Breakdown by Category	
Concrete	$240
Penstock	$3,600
Turbine	$340
Transmission Material	$120
Technical Expertise	$1,600
Electrical Equipment	$46,300
Total Cost	**$52,200**

8.0 Construction Schedule

A construction schedule was created to estimate the amount of time required to construct this micro hydropower system as well as to identify the critical tasks of the project. The project tasks can be broken into three phases; generation, transmission, and distribution. These phases are almost completely independent of each other, and each contains separate critical paths. All of the civil and mechanical tasks, including a portion of the electrical tasks, make up the generation phase. This includes the intake and penstock construction as well as the manufacturing of the turbine and installation of the generator. The transmission section covers the installation of power poles and power lines. The distribution stage is specifically associated with construction of the electrical distribution system within the community of Piriatí. An estimated labor force of 50 individuals and 5 beasts of burden were assumed based on information collected while in the community. The full labor force would be required to carry in the construction supplies to the construction site. This estimate was determined by considering the total weight of the required materials compared to the amount of weight which could be carried by each individual and the time required to make the journey. The current schedule estimates that the project will require five months to complete. The community's availability and an ample source of funding will determine the actual start of the project. However, the most feasible season for construction must be considered as well due to the extreme weather changes. It has been identified that December to April is the dry season, but whether or not this is the optimum time for construction is still undetermined. The project schedule can be seen in Appendix E: Design Schedule.

9.0 Conclusions & Recommendations

Two possible solutions have been proposed to provide electrification via hydropower generation to the rural village of Piriatí Emberá; these sites are identified as Cascada Pequeña and Alan's Falls. This report provides an introduction to the available resources that can be used in creating a sustainable electrification system in this community to replace diesel generation. It is being suggested that this initial design should be handed over to a future International Senior Design group for further study and development.

One recommendation for continued study is to collect more survey and topographical information about the two proposed sites. This would include collecting extensive GPS coordinates of the two waterfalls as well as the possible routes for the water diversion. If it is deemed necessary to conduct a theodolite survey of the sites, the existing benchmarks should still be visible, and their coordinates have been included in a digital appendix on the provided compact disc. A municipal GPS benchmark was also identified on southeast corner of the bridge which crosses the Piriatí River. This benchmark could be used to tie the collected survey points to the municipal or national grid. This may be important since the collected GPS points do not overlay properly with Google Earth's maps. This is apparent especially with the "bridge" landmark point featured in Figure 9 of Appendix D: Watershed Delineation Map.

A reference that had been given to the team during the design process is a company named Kiser Engineering, a hydroelectric industry company based out of Norway, Michigan in the Upper Peninsula. It is recommended that they be contacted in the future for possible final design review and suggestions.

The team contacts with connections to our site in Panama have also been given drafts of the alternative analysis and preliminary design to verify in country costs and a review of the chosen generator site. Much is left to do concerning a feasible design for a micro-hydropower system for the community of Piriatí in Panama, but progress has been steady. As a result of selecting the primary generator site, finalizing flow rates, and specifying primary electrical components, future work can continue to move forward.

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Appendix A: Community Surveys

Community Interviews

Table 4: Community Surveys (1-9 Emberá Community, 10-17 Spanish Community Interviews)

Category	Interview 1	Interview 2	Interview 3	Interview 4	Interview 5	Interview 6	Interview 7	Interview 8	Interview 9	Interview 10	Interview 11	Interview 12	Interview 13	Interview 14	Interview 15	Interview 16	Compiled Community Surveys
Family Size	2	8	7	3	12	4	7	6	4	2	1	5	1	5	1	4	4.5
Occupation	Store Owner	Farmer	Farmer	Farmer	Farmer	Farmer	Teek Farmer	Farmer	Farmer	Farmer	Farmer	Farmer	Farmer	Farmer	Farmer	Farmer, Artisan Work	Farmer, Store Owner, Artisan
Income (mo.)	20	50	80	45	30	40	50	35	25	25	25	25	25	25	25	100	39
Water Payment (mo.)	1	1	1	1	1	1	1	1								1	1
Connected To Generator	Yes	Yes	Yes	Yes	No	Yes	No	Yes								Yes	Yes
Spend on Diesel (wkly)	7	1	1	1	-	1	-	1								2	2
Installation Cost	15	10	10	20	Far Distance (Wire Costly)	Costly	-	10								10	12.5
Happy With Current System	No	No	No	No	-	No	No Major Reason	No								No	No
Appliances	TV, Lights, Sound System, Washing Machine	TV, Iron, Lights	Lights, TV	TV, 2 Light bulbs	TV, Lights	TV, DVD, Boom Box, Lights	Lights, TV	TV, Lights, Iron, Recharging Cell Phones	Fan, Lights, TV	Lights, TV, Fan	Washing Machine Lights	Washing Machine, TV, Fridge	Washing Machine, Fan, Iron	Iron, Lights, TV	Lights, Fridge, TV	Lights, Washing Machine, TV, Cutting Hair	Lights, Washing Machines, TV, Fan, Fridge, Iron
Economic Activates	Fridge, Work After Dark	School, Butcher	Fridge To Sell Cool Items	Washing Machine, Fridge	Radio, Washing Machine	No Other Economic Interests	Washing Machine	Fridge To Sell Cool Items								Cut hair in evening, tools for artisan work, drilling beads	Selling Cool Items, Washing Machine, Butcher
Volunteer Work Time	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Willing To Pay (mo.)**	Depends	12	Depends	Whatever The Price	Willing to Pay	Depends	Interested In New System	Willing To Pay More								Willing To Pay More	50/50 Willing To Pay More/ Depends
Light With Presently	-	-	-	-	-	-	-	-	Candles	Candles	Flashlight	Candles & Flashlight	Kerosene	Kerosene	Kerosene	-	
Cost To Light (wkly)	-	-	-	-	-	-	-	-	1.4	2	1	1.5	0.6	1	1.5	-	

** Based on a system that runs 24/7

Note: Did not include school survey data on this sheet, the questions were too different

Estimated Power Demand from Community Surveys

Table 5: Estimated Community Power Demand

Commonly Requested Items	Watts	Number In Use at A Given Time	Total Watts	kilowatts
Light (Incandescent)	100	50	5000	5
Light (Fluorescent)	30	100	3000	3
TV	44	10	440	0.44
Fan (Box Fan)	96	20	1920	1.92
Boom Box	12	20	240	0.24
Computer (Laptop)	35	0	0	0
Computer (Desktop)	117.5	1	117.5	0.1175
Fridge/Freezer (16 cubic feet) Conventional	475	5	2375	2.375
Freezer Conventional (14 cubic feet)	350	5	1750	1.75
Washing Machine (Automatic)	500	5	2500	2.5
Washing Machine (Manuel)	300	0	0	0
Iron	1000	3	3000	3
Total	3059.5		20342.5	**20.34**

From this estimation the ideal system should generate about 15-20kilowatts of power in order to meet the estimated demand of the community. Some of the items included in the power demand analysis include light bulbs, radios, fans, freezers, computers, and televisions.

Photographical Figure 1: Sample current house wiring for many homes in Piriatí. Note only one outlet is installed per home.

Appendix B: Site Data, Penstock Design Calculations, and Flow Rates

Site Data

Table 6: Google Map Watershed Delineation (Flow Rates Estimated Off Of Cascada Pequeña)

Waterfall Site	Area (km^2)	Percent of Total Area	Flow Rate (lps)
Cascada Pequeña	23.7	100.00%	969
Alan's Falls	3.7	15.40%	149
Tito's Upper Falls	4.9	20.86%	202
Tito's Lower Falls	4.9	20.86%	202
The Toma	1.5	6.45%	63

Table 7: Compiled Site Data

Waterfall Site	Transmission Distance (Km)	Potential Head (m)	Flow Rate (lps)	Potential Power (kW)
Cascada Pequeña	2.6	2.1	969	4.2
Cascada Pequeña w/ PC	1.1	9.1	309	7.4
Alan's Falls	5.5	22.9	149	9.9
Tito's Upper Falls	7.2	22.9	202	13.8
Tito's Lower Falls	7.0	24.4	202	14.7
The Toma	7.1	61.0	62	9.3

Table 8: Power to Distance Analysis

Waterfall Site	Transmission Distance (Km)	Potential Power (kW)	Power/Distance
Cascada Pequeña	2.6	4.2	1.62
Cascada Pequeña w/ PC	1.1	7.4	6.76
Alan's Falls	5.5	9.9	1.80
Tito's Upper Falls	7.2	13.8	1.92
Tito's Lower Falls	7.0	14.7	2.10
The Toma	7.1	9.3	1.31

Penstock Design Calculations

Table 9: Penstock Design: Cascada Pequeña

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)
7	1000	0.01	3.33	2.50	4.91	0.68	0.5	0.55	3.00	7.07	6.96	**1.09**
7	1000	0.01	6.67	2.50	4.91	1.36	0.5	0.55	3.00	7.07	6.86	**2.14**
7	1000	0.01	10.00	2.50	4.91	2.04	0.5	0.55	3.00	7.07	6.68	**3.12**
7	1000	0.01	11.00	2.50	4.91	2.24	0.5	0.55	3.00	7.07	6.61	**3.40**
7	1000	0.01	12.00	2.50	4.91	2.44	0.5	0.55	3.00	7.07	6.54	**3.67**
7	1000	0.01	13.00	2.50	4.91	2.65	0.5	0.55	3.00	7.07	6.46	**3.93**
7	1000	0.01	14.00	2.50	4.91	2.85	0.5	0.55	3.00	7.07	6.37	**4.17**
7	1000	0.01	15.00	2.50	4.91	3.06	0.5	0.55	3.00	7.07	6.28	**4.40**
7	1000	0.01	16.00	2.50	4.91	3.26	0.5	0.55	3.00	7.07	6.18	**4.62**
7	1000	0.01	17.00	2.50	4.91	3.46	0.5	0.55	3.00	7.07	6.07	**4.83**

Table 10: Penstock Design: Alan's Falls

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)	Δ kW
75	800	0.01	3.00	0.50	0.20	15.28	0.5	0.55	3.00	7.07	15.19	**2.13**	--
75	800	0.01	3.00	0.67	0.35	8.59	0.5	0.55	3.00	7.07	60.66	**8.51**	6.38
75	800	0.01	3.00	0.83	0.55	5.50	0.5	0.55	3.00	7.07	70.25	**9.86**	1.35
75	800	0.01	3.00	1.00	0.79	3.82	0.5	0.55	3.00	7.07	73.07	**10.25**	0.40
75	800	0.01	3.00	1.33	1.39	2.16	0.5	0.55	3.00	7.07	74.53	**10.46**	0.20

Table 11: Penstock Design: Tito's Upper

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)	Δ kW
75	100	0.01	1.00	0.33	0.09	11.46	0.5	0.55	3.00	7.07	67.86	**3.17**	--
75	100	0.01	2.00	0.33	0.09	22.92	0.5	0.55	3.00	7.07	46.45	**4.35**	1.17
75	100	0.01	3.00	0.67	0.35	8.59	0.5	0.55	3.00	7.07	72.70	**10.20**	5.86
75	100	0.01	4.00	0.67	0.35	11.46	0.5	0.55	3.00	7.07	70.92	**13.27**	3.07
75	100	0.01	4.00	0.83	0.55	7.33	0.5	0.55	3.00	7.07	73.58	**13.77**	0.50
75	100	0.01	4.00	1.00	0.79	5.09	0.5	0.55	3.00	7.07	74.39	**13.92**	0.15

Table12: Penstock Design: Tito's Lower

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)	Δ kW
80	100	0.01	1.00	0.33	0.09	11.69	0.5	0.55	3.00	7.07	72.51	**3.39**	--
80	100	0.01	2.00	0.66	0.34	5.85	0.5	0.55	3.00	7.07	78.93	**7.38**	3.99
80	100	0.01	3.00	0.66	0.34	8.77	0.5	0.55	3.00	7.07	77.59	**10.89**	3.50
80	100	0.01	4.00	0.66	0.34	11.69	0.5	0.55	3.00	7.07	75.72	**14.17**	3.28
80	100	0.01	4.00	0.83	0.55	7.33	0.5	0.55	3.00	7.07	78.58	**14.70**	0.53
80	100	0.01	4.00	0.83	0.55	7.33	0.5	0.55	3.00	7.07	78.58	**14.70**	0.00

Table 13: Penstock Design: The Toma

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)	Δ kW
200	2800	0.01	0.50	0.50	0.20	2.55	0.5	0.55	3.00	7.07	194.31	**4.54**	--
200	2800	0.01	0.75	0.50	0.20	3.82	0.5	0.55	3.00	7.07	187.20	**6.57**	2.02
200	2800	0.01	1.00	0.67	0.35	2.86	0.5	0.55	3.00	7.07	194.58	**9.10**	2.53
200	2800	0.01	1.00	0.67	0.35	2.84	0.5	0.55	3.00	7.07	194.72	**9.11**	0.01
200	2800	0.01	1.00	0.83	0.54	1.85	0.5	0.55	3.00	7.07	198.18	**9.27**	0.16

Sample Calculations for power exiting penstock (P_p) : (Morris)

Potential Power (kilowatts):

$$H_t = H_0 - H_L - \frac{V_3^2}{2g} = Z_1 + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} - \frac{V_3^2}{2g}, \text{ (Energy Equation)}$$

$$H_L = \sum K_i \frac{V_1^2}{2g} + f \frac{L}{D} \frac{V_1^2}{2g}, \text{ (includes minor losses—inlet, bends—and friction losses)}$$

$$\therefore H_t = H_0 - \left(\sum K_i \frac{V_1^2}{2g} + f \frac{L}{D} \frac{V_1^2}{2g}\right) - \left(\frac{A_1^2}{A_3^2}\right) \frac{V_1^2}{2g}$$

Power (kilowatts) = $\gamma Q H_t \varepsilon$ / 737, Where γ= 62.4$\frac{\text{lbs}}{\text{ft}^3}$, Q=Flow Rate ($\frac{\text{ft}^3}{s}$), H= head (feet) ε=0.65*0.85=0.5525

Note: Metric Units do not convert with this equation. A different denominator is necessary.

Flow Rate Calculations for Cascada Pequeña

Table 14: Profile of Cascada Pequeña

Station (m)	Depth (in)	Location	Velocity (ft/s)
0	19.25	L	0.34
5	17.5	L	0.34
10	27.75	ML	0.6
15	34.5	ML	0.6
20	29.25	MR	0.61
25	18.4	MR	0.61
30	9.6	R	0.37
34.5	0	R	0.37

Table 15: Flow Rate for Cascada Pequeña

Downstream Cascada Pequeña					
Station (ft)	Depth (in)	Location	Velocity (ft/s)	Area (ft^2)	Flow Rate (ft^3/s)
0	19.25	L	0.34	8.02	2.73
5	17.5	L	0.34	7.29	2.48
10	27.75	ML	0.6	11.56	6.94
15	34.5	ML	0.6	14.38	8.63
20	29.25	MR	0.61	12.19	7.43
25	18.4	MR	0.61	7.67	4.68
30	9.6	R	0.37	3.60	1.33
34.5	0	R	0.37	--	--
Total (cfs)					34
Total (lps)					**969**

Note: Conversion 28.32 Liters in 1 cf (Google Converter)

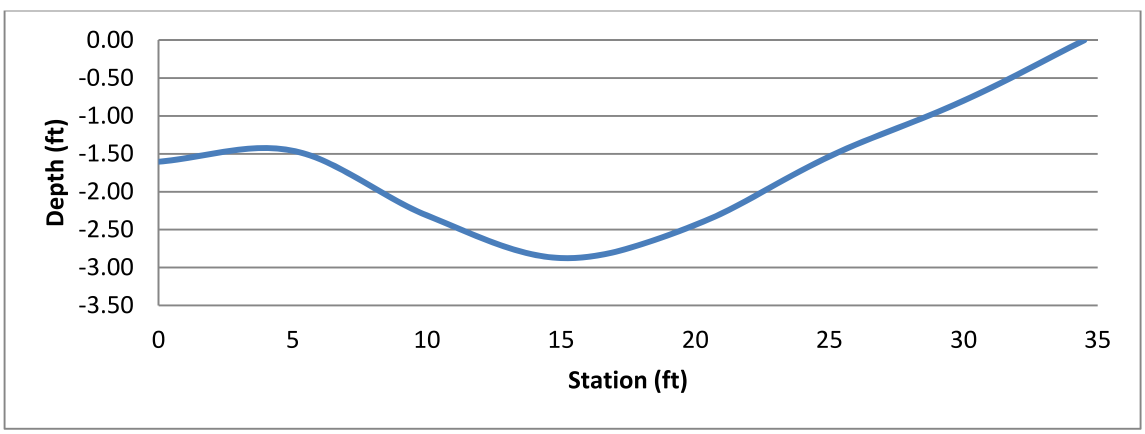


Figure 10: Profile of Cascada Pequeña

Pressure Calculations

Alan's Falls:

$$Pressure\ Head = 75ft$$

$$Unit\ Weight\ of\ Water\ (\gamma)\text{: } 62.4\frac{lbs}{ft^3}$$

$$Pressure(\psi) = \frac{P}{\gamma}$$

$$\boldsymbol{P_{Max} = \psi * \gamma = 75ft * 62.4\frac{lbs}{ft^3} * \left(\frac{1}{144}\right) = 32.5psi\ (224.1\ kPa)}$$

Cascada Pequeña:

$$Pressure\ Head = 7ft$$

$$Unit\ Weight\ of\ Water\ (\gamma)\text{: } 62.4\frac{lbs}{ft^3}$$

$$Pressure(\psi) = \frac{P}{\gamma}$$

$$P_{Max} = \psi * \gamma = 7ft * 62.4\frac{lbs}{ft^3} * \left(\frac{1ft^2}{144in^2}\right) = 3.0psi\ (20.7\ kPa)$$

Tito's Lower Falls:

$$Pressure\ Head = 80ft$$

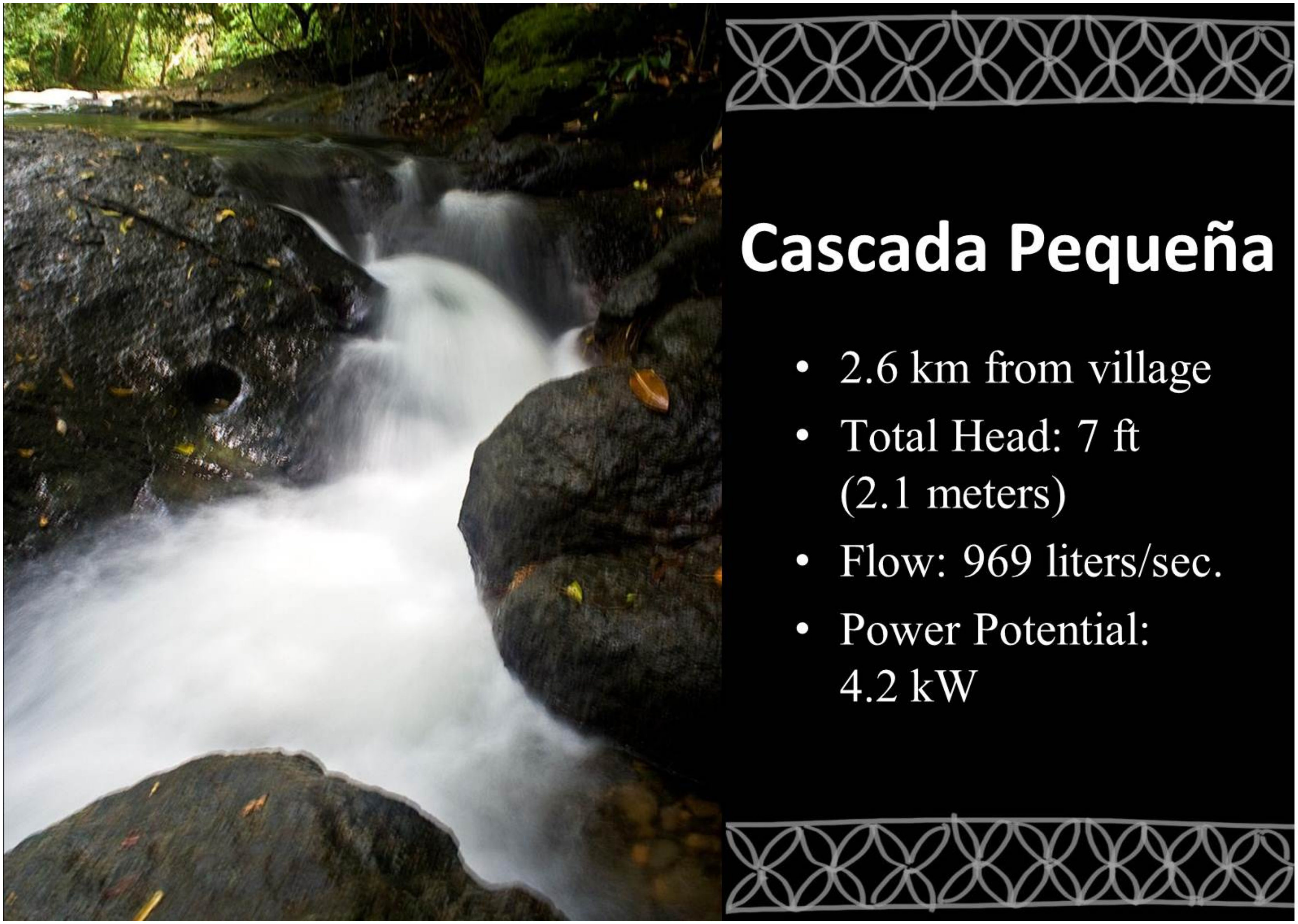
$$Unit\ Weight\ of\ Water\ (\gamma)\text{: } 62.4\frac{lbs}{ft^3}$$

$$Pressure(\psi) = \frac{P}{\gamma}$$

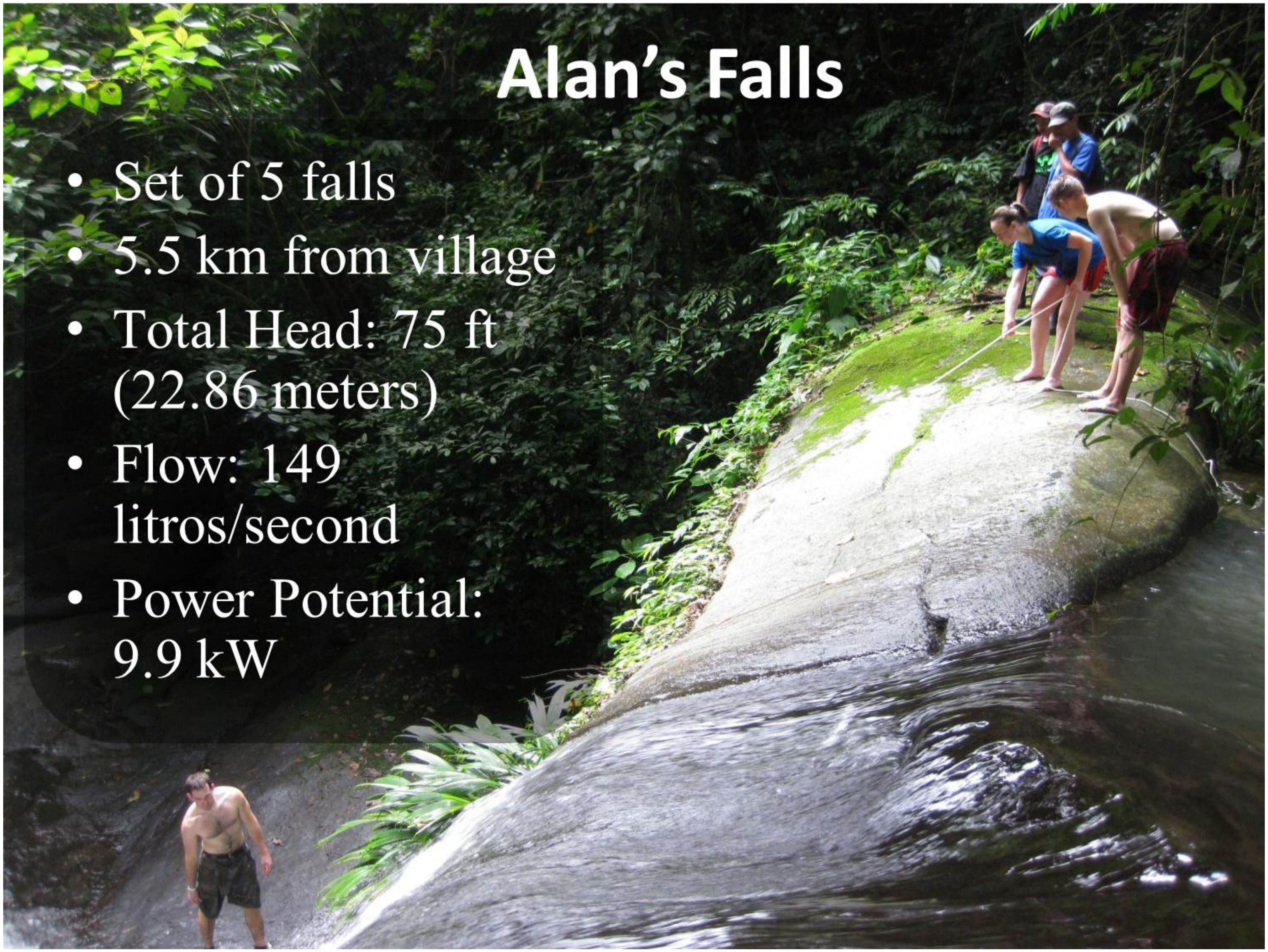
$$P_{Max} = \psi * \gamma = 75ft * 62.4\frac{lbs}{ft^3} * \left(\frac{1}{144}\right) = 35.0psi\ (241.3\ kPa)$$

Site Summary

Cascada Pequeña

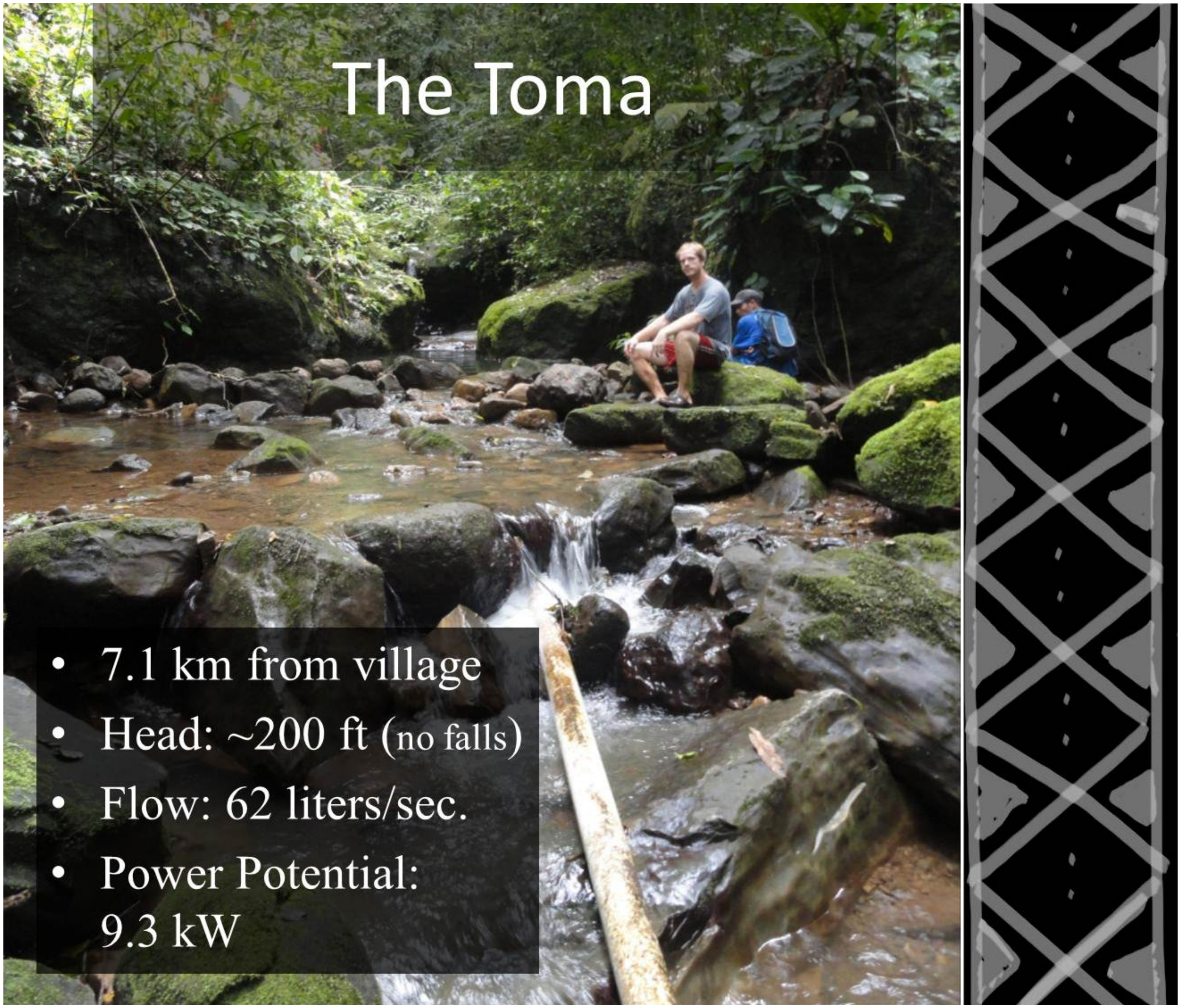


Alan's Falls


Alan's Falls
• Set of 5 falls
• 5.5 km from village
• Total Head: 75 ft (22.86 meters)
• Flow: 149 litros/second
• Power Potential: 9.9 kW

Tito's Upper Falls

The Toma

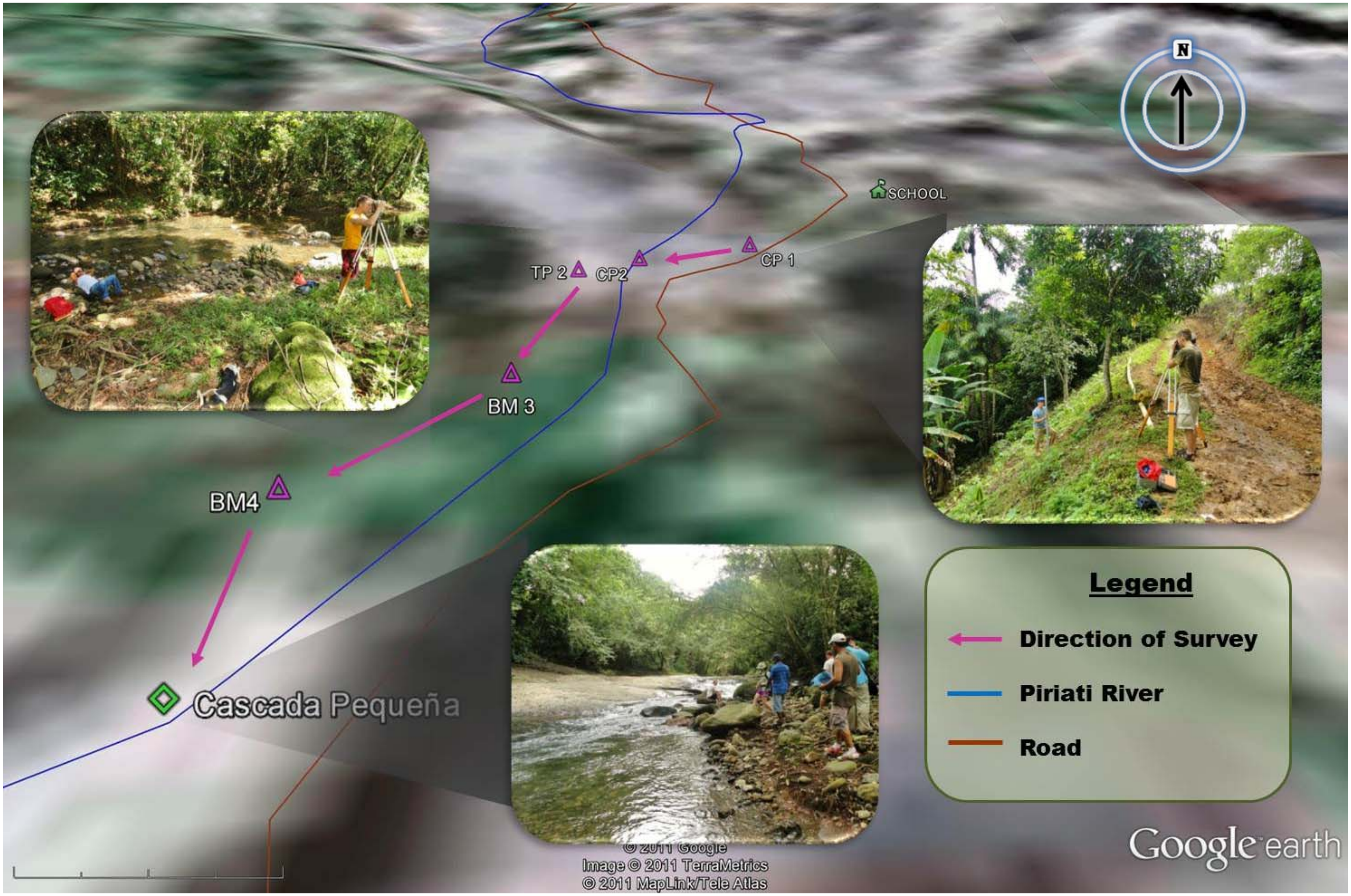

The Toma
• 7.1 km from village
• Head: ~200 ft (no falls)
• Flow: 62 liters/sec.
• Power Potential: 9.3 kW

Appendix C: Survey Data

Table 16: Cascada Pequeña Survey Data

Info		Location: Cascada Pequeña Date: Aug. 13th 2011 Weather: Overcast Humid	Theodolite Survey Data				Tasks	Intrument: J. Wiljanen Rod: A. Baril Scribe: T. Fincher	
Top (ft)	**Center (ft)**	**Bottom (ft)**	**H.I.**	**Assumed Elev (ft)**	**Stadia (Degree)**	**Vert. Angle (Degree)**	**Height (ft)**	**Horiz. Distance (ft)**	**Description**
3.06	2.65	2.24	989.64	1000.00	114.79	9.25	13.01	79.88	Pink Rock BS (BM#1)
5.17	4.99	4.81		991.73	160.58	11.58	7.08	34.55	Flood Plain Max
5.83	5.66	5.49		983.98	205.24	0.00	0.00	34.00	Lower Flood Plain
7.99	7.83	7.68		981.81	29.84	0.00	0.00	31.00	Rock Edge
10.32	10.14	9.95		979.50	244.56	0.00	0.00	37.00	Rio Edge
11.56	11.28	10.99		978.36	255.49	0.00	0.00	57.00	Rio Center Line
10.46	10.10	9.74		979.54	264.35	0.00	0.00	72.00	Rio Edge
4.89	4.40	3.91		985.24	278.89	0.00	0.00	98.00	Upper Ridge
1.29	0.70	0.11		983.52	240.71	-2.63	-5.42	117.75	BM 2 "Pink Spk in Tree"
5.01	4.17	3.34	987.69	*983.52*	1.78	0.00	0.00	167.00	BM 2 BS
2.63	1.56	0.50		987.50	215.80	0.37	1.36	212.99	TP 3 "Top of Stump"
2.93	2.16	1.40	993.62	987.50	32.92	-1.48	-3.96	152.90	TP 3 BS
2.41	2.08	1.76		995.31	47.15	3.33	3.77	64.78	BM #3 "Pink Spk in Tree"
4.93	4.51	4.10		997.12	322.84	5.57	8.01	82.22	Upper Plot #1
1.51	1.34	1.18		993.88	5.18	2.78	1.60	32.92	Upper Plot #2
1.20	0.98	0.76		989.21	21.02	-4.48	-3.43	43.73	Lower Plot #1
11.15	10.91	10.68		982.71	58.53	0.00	0.00	47.00	Edge Rio
2.58	2.23	1.88		982.78	91.72	-7.12	-8.61	68.93	Edge Rio
2.49	1.52	0.56		990.02	204.48	-0.62	-2.08	192.98	BM #4 "Pink Spk in Tree"
3.22	2.71	2.20	992.73	*990.02*	24.74	0.00	0.00	102.00	BM#4 BS
5.08	4.77	4.48		1002.76	247.80	14.78	14.80	56.09	Upper Slope
7.99	7.78	7.59		984.95	205.19	0.00	0.00	40.00	Edge Rio
8.49	8.23	7.97		984.50	183.45	0.00	0.00	52.00	Rio Center Line
8.08	7.73	7.39		985.00	159.43	0.00	0.00	69.00	Edge Rio
2.93	2.55	2.18		990.18	152.79	0.00	0.00	75.00	Upper Slope
1.84	1.03	0.21		990.70	194.71	-0.35	-1.00	162.99	BM #5 "Pink Spk in Tree"
2.32	1.41	0.50	995.24	*990.70*	19.63	-0.98	-3.12	181.95	BM #5 BS
6.24	6.08	5.91		989.16	339.06	0.00	0.00	33.00	Center Line Waterfall
6.00	5.76	5.51		989.48	304.84	0.00	0.00	49.00	Edge Waterfall
2.58	2.29	1.99		992.95	198.38	0.00	0.00	59.00	East Slope
5.55	5.25	4.97		989.99	213.40	0.00	0.00	58.00	Edge Rio
7.64	7.34	7.04		987.90	223.20	0.00	0.00	60.00	In The River
7.09	6.77	6.45		988.47	231.03	0.00	0.00	64.00	In The River
5.76	5.38	5.00		989.86	244.61	0.00	0.00	76.00	Edge River
5.07	4.67	4.27		993.36	251.39	2.00	2.79	79.90	West Slope

Map of Survey



Appendix D: Site and Watershed Delineation Map

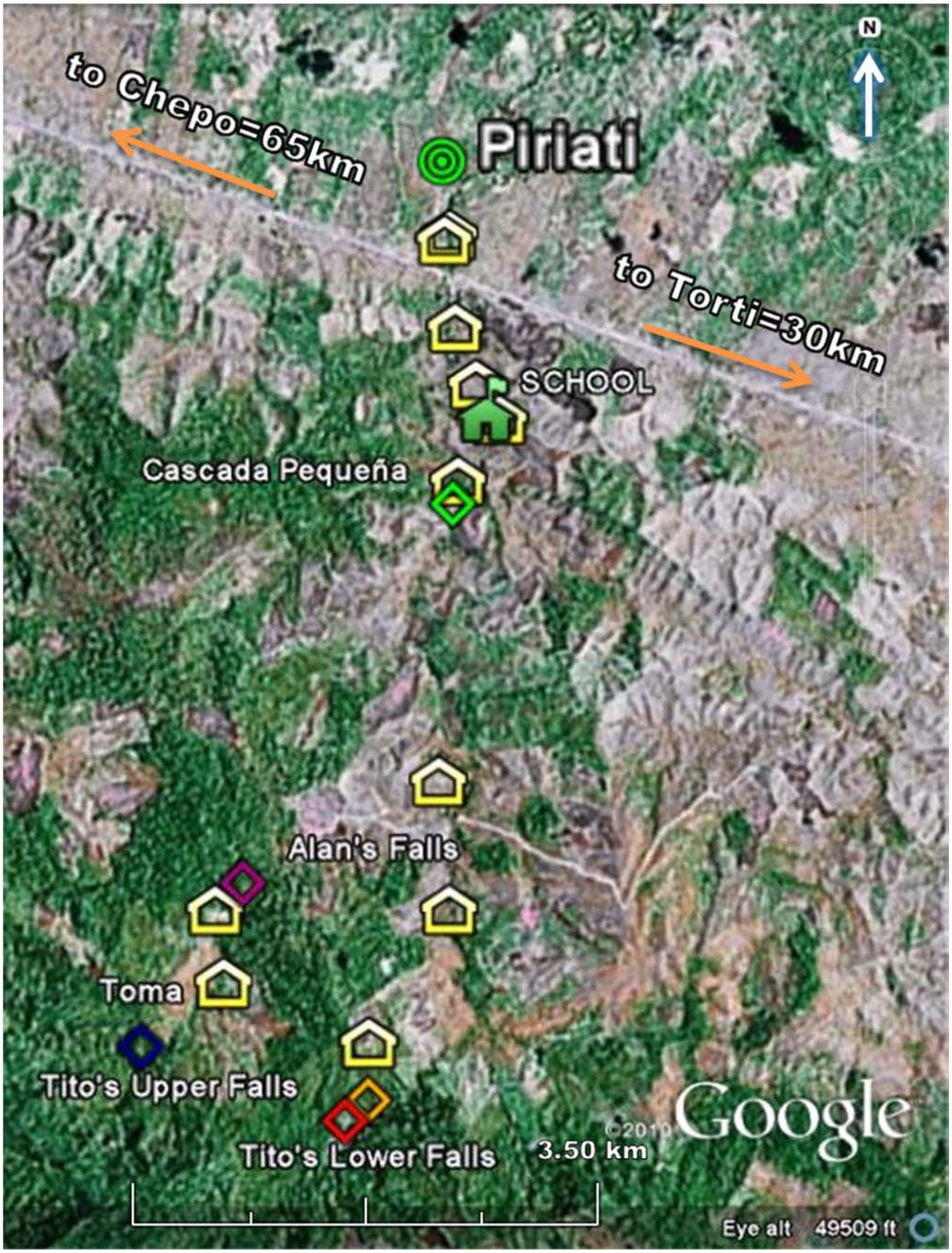


Figure 11: Site Map

Google Earth site map includes the location of all the houses visited in Piriatí Arriba, indicated with yellow house as well as each potential waterfall site which are labeled and indicated with multi-colored diamonds. The data used to create this map was collected using a personal Garmin GPS.

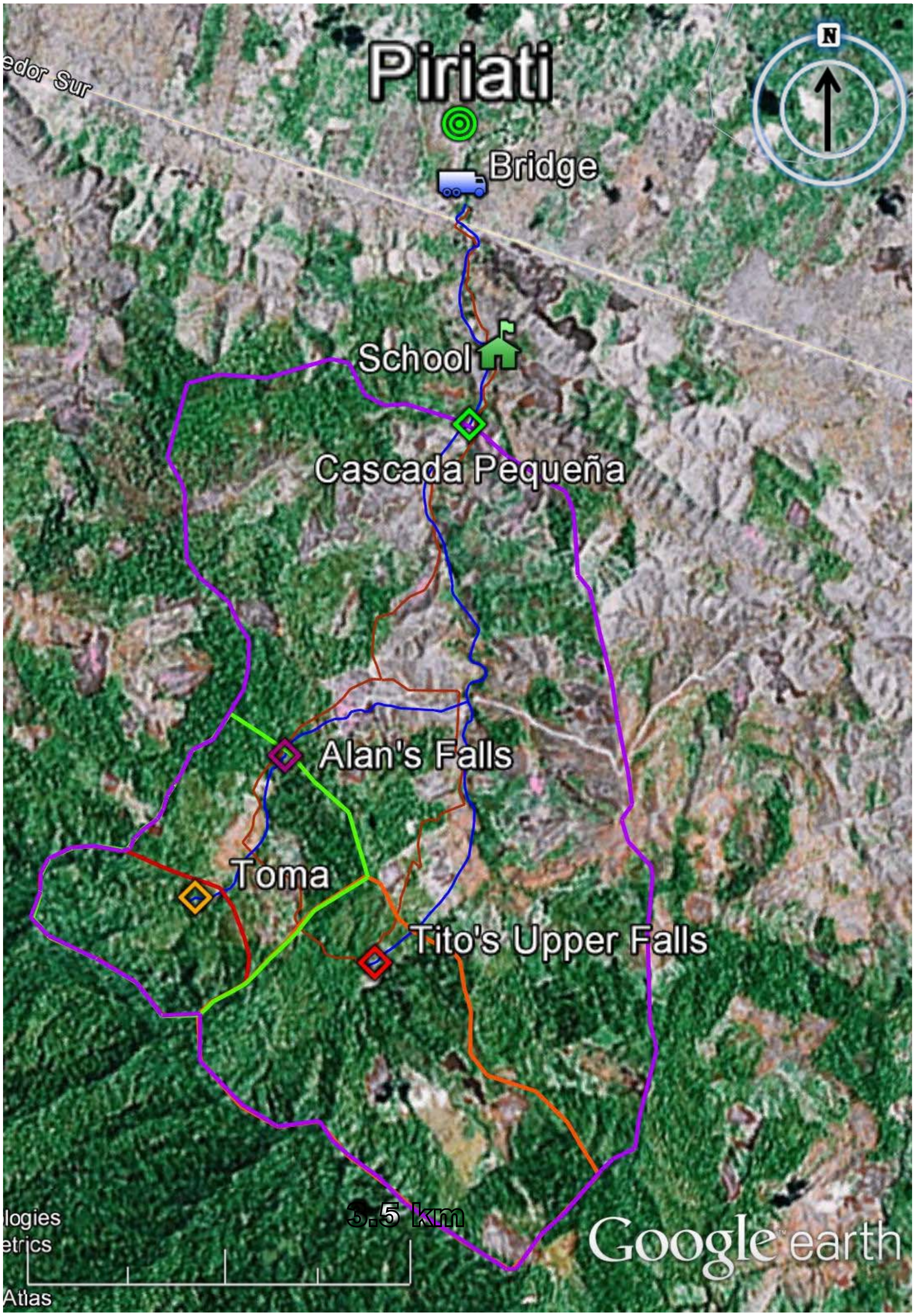


Figure 12: Watershed Delineation

This figure displays the overall watershed area for Cascada Pequeña, Alan's Falls, The Toma, and Tito's upper and lower falls. Alan's Falls has approximately 15% of the total contributing area to Cascada Pequeña. From this estimate Alan's falls has 85% less flow then Cascada Pequeña.

Appendix E: Work Breakdown Structure and Design Schedule

Table 17: Work Breakdown Structure

No.	Activity	Lead	Support
	Ye-Yé Engineering		
1.0	Team Logo, Mission Statement	Becca	Tyler
2.0	Preliminary Cost Estimating	Alex	Becca
3.0	Mapping, Data Collection and Analysis	Kate	Tyler
4.0	Work Breakdown Structure and Design	Tyler	Kate
5.0	Status Report # 1 (PP)**	Josh	Team
6.0	Preliminary Alternatives Analysis	Kate	Tyler
7.0	Material Costs	Alex	External Review
8.0	Refined Alternative Analysis	Team	Dave/Mike
9.0	Design Scheme Memo (60% of Design)	Becca	Team
10.0	D80 Presentations	Tyler	Team
11.0	Reports, Posters, and Oral Presentation (D80)	Team	Dave/Mike
12.0	Status Report #2	Alex	Becca
13.0	Status Report #3	Kate	Tyler
14.0	Cost Estimate and Schedule	Tyler	Kate
15.0	Status Report #4	Josh	Kate
16.0	Draft Final Report	Tyler	Josh
17.0	Draft Poster	Kate	Becca
18.0	Final Project Presentations	Becca	Josh
19.0	Final Information (Due @ Noon)	Team	External Review
	Mechanical Engineering		
20.0	Turbine Selection	Josh	External Review
21.0	Mechanical 3D Modeling	Josh	External Review
22.0	Finite Element Analysis	Josh	External Review
	Electrical Engineering		
23.0	Generator and Turbine Design	Becca	Alex
24.0	Energy Analysis	Alex	Becca
25.0	Power Electronics	Becca	Alex
26.0	Energy Distribution	Alex	Becca
	Civil Engineering		
27.0	Flow Rate Analysis	Kate	Tyler
28.0	Penstock Design	Tyler	Kate
29.0	Site Planning	Kate	Tyler
30.0	Stream Flow Modeling	Kate	Tyler
31.0	Watershed Delineation	Tyler	Kate
32.0	Site Modeling	Tyler	Kate

Activities:

1.0 Team Logo, Mission Statement
- 1.1 Design and critique logo.
- 1.2 Develop a mission statement for organization.
- 1.3 Draft memo to inform faculty of selections.

2.0 Preliminary Cost Estimating
- 2.1 Approximate material costs from manufactures and online sources.

3.0 Mapping, Data Collection and Analysis
- 3.1 Import GPS data into Google Earth and AutoCAD.
- 3.2 Compile transit-stadia survey data and map in AutoCAD.
- 3.3 Locate and purchase topographical maps.
- 3.4 Compile community surveys.

4.0 Work Breakdown Structure and Design Schedule
- 4.1 Draft work breakdown structure and design schedule.
- 4.2 Edit drafts to be submitted.

5.0 Status Report # 1
- 5.1 Draft report.
- 5.2 Edit and submit report.
- 5.3 Design presentation slides.
- 5.4 Give presentation to peers and faculty as well as turn in a copy of the slides.

6.0 Preliminary Alternatives Analysis
- 6.1 Draft initial alternatives analysis.
- 6.2 Use analysis to reduce alternatives down to three

7.0 Material Costs
- 7.1 Compile list of all materials need for project.
- 7.2 Obtain accurate material costs from manufactures.
- 7.3 Confirm material costs with in-country sources.

8.0 Refined Alternative Analysis
- 8.1 Create site specific cost estimates.
- 8.2 Reduce alternatives to primary and secondary status based on revised costs.

9.0 Design Scheme Memo (60% of Design)
- 9.1 Review progress of project as defined in the design schedule.
- 9.2 Draft report to include the most current design.
- 9.3 Edit and submit report.

10.0 D80 Presentations
- 10.1 Begin designing presentation slides for D80 conference.

11.0 Reports, Posters, and Oral Presentation (D80)
- 11.1 Design poster for break out session.
- 11.2 Create hands-on group activity.
- 11.3 Finalized presentation slides.
- 11.4 Practice oral presentation.

12.0 Status Report #2

12.1 Draft report.
12.2 Edit and submit report.
12.3 Design presentation slides.
12.4 Give presentation to peers and faculty as well as turn in a copy of the slides.

13.0 Status Report #3
13.1 Draft report.
13.2 Edit and submit report.
13.3 Design presentation slides.
13.4 Give presentation to peers and faculty as well as turn in a copy of the slides.

14.0 Cost Estimate and Schedule
14.1 Finalize total project costs to include material, labor, and overhead costs
14.2 Compile potential funding sources for the benefit of the community.
14.3 Complete timeline for project schedule.

15.0 Status Report #4
15.1 Draft report.
15.2 Edit and submit report.
15.3 Design presentation slides.
15.4 Give presentation to peers and faculty as well as turn in a copy of the slides.

16.0 Draft Final Report
16.1 Compile report to include final design specifications.
16.2 Edit and submit report.

17.0 Draft Poster
17.1 Create final poster design
17.2 Edit and submit poster draft

18.0 Final Project Presentations
18.1 Draft design slides
18.2 Initial rehearsal for presentation
18.3 Finalize presentation slides
18.4 Final rehearsal

19.0 Final Information
19.1 Make corrections to previously submitted material based on critiques
19.2 Submit final report, final poster, and final presentation slides.

***Mechanical Engineering Activities*:**

20.0 Turbine Selection
21.0 Mechanical 3D Modeling
22.0 Finite Element Analysis

Electrical Engineering Activities:

23.0 Generator and Turbine Design
- 23.1 Establish appropriate basic design of turbine for each site under review.
- 23.2 Evaluate an appropriate generator capacity for each site location
- 23.3 Create an appropriate connection between turbine and generator in design

24.0 Energy Analysis
- 24.1 Determine the most efficient output schematic for each site
- 24.2 Develop a cost effective way to capitalize on the resources of each site to maximize output

25.0 Power Electronics
- 25.1 Identify any usable power electronics that could help with transmission and regulation
- 25.2 Provide cost analysis on usable power electronics
- 25.3 Define detailed parameters of use for each piece of equipment
- 25.4 If applicable, design site-specific electronics for use (based on need)

26.0 Energy Distribution
- 26.1 Develop distribution that will utilize existing system
- 26.2 Determine the usage of single or three phase distribution
- 26.3 Identify all components needed for appropriate distribution
- 26.4 Choose and identify the usage of buried cables versus overhead distribution

Civil Engineering Activities:

27.0 Flow Rate Analysis
- 27.1 Revise flow rate data.
- 27.2 Tabulate and refine collected flow rate information.
- 27.3 Establish best approximated flow rates for all potential design sites.

28.0 Penstock Design
- 28.1 Design penstock layout from each primary and secondary alternative.
- 28.2 Final Penstock design should seek to minimize frictional losses as well as piping costs while still considering wiring transmission costs and the overall lay of the land.

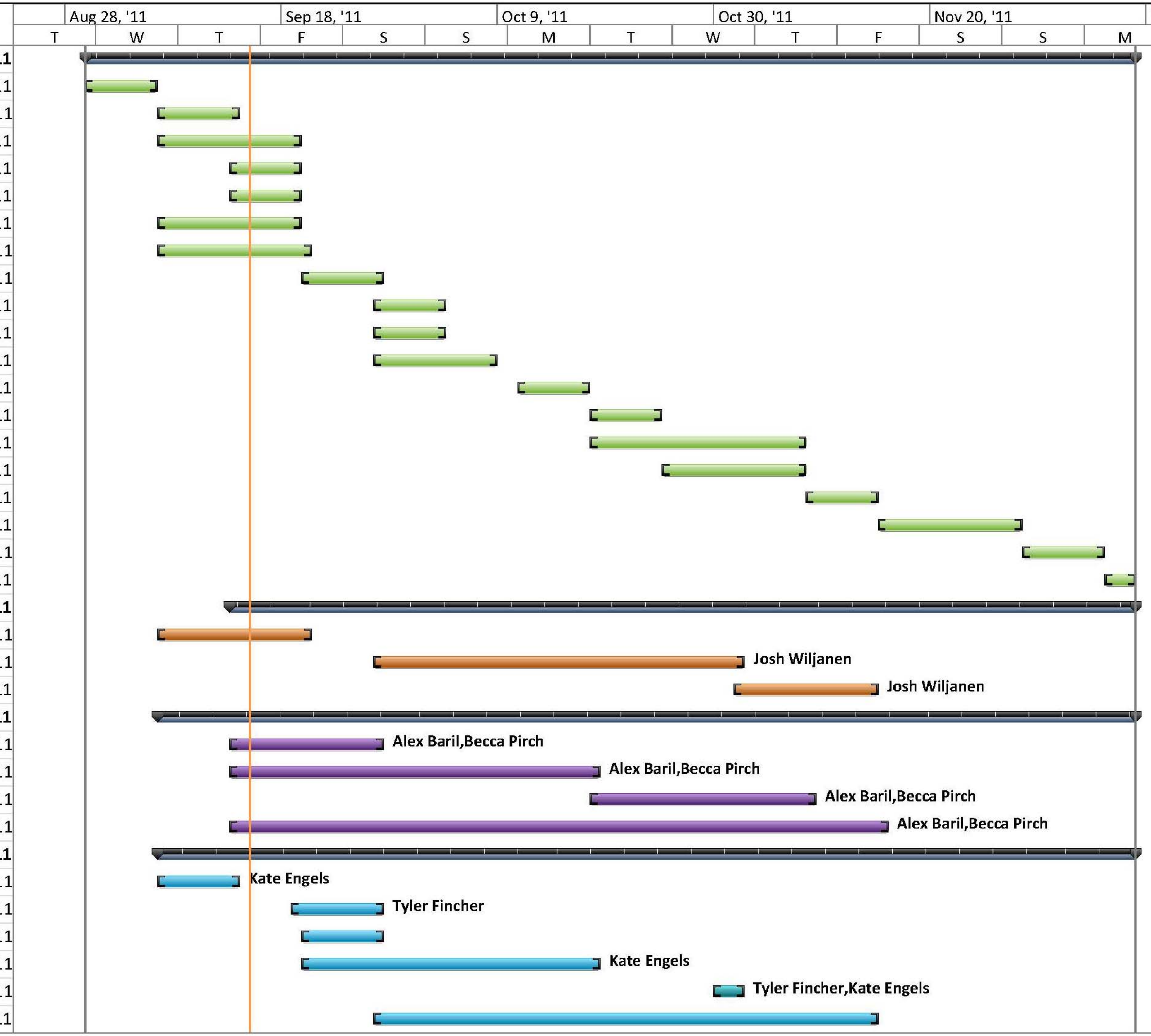
29.0 Site Planning
- 29.1 Design turbine and generator layout for primary site.
- 29.2 Design turbine and generator layout for secondary sites.

30.0 Stream Flow Modeling
- 30.1 Graph of stream bed cross section.
- 30.2 Model flow rates in HEC-RAS or HEC-HMS.

31.0 Watershed Delineation
- 31.1 Use gathered topographical maps to locate Piriatí river watershed.
- 31.2 Use delineated watershed area to interpolate missing flow rates, validate existing flow rates, and estimate seasonal high and low flow rates.

32.0 Site Modeling
- 32.1 Create 3D site model in Google Sketch Up based on final site plan and final generator design for primary site.

ID	Task Name	Duration	Start	Finish
1	**Ye-Yé Engineering**	**74 days**	**Tue 8/30/11**	**Fri 12/9/11**
2	Team Logo, Mission Statement	5 days	Tue 8/30/11	Mon 9/5/11
3	Preliminary Cost Estimating	6 days	Tue 9/6/11	Tue 9/13/11
4	Mapping, Data Collection and Analysis	10 days	Tue 9/6/11	Mon 9/19/11
5	Work Breakdown Structure and Design	5 days	Tue 9/13/11	Mon 9/19/11
6	Status Report # 1	5 days	Tue 9/13/11	Mon 9/19/11
7	Priliminary Alternatives Analysis	10 days	Tue 9/6/11	Mon 9/19/11
8	Material Costs	11 days	Tue 9/6/11	Tue 9/20/11
9	Refined Alternative Analysis	6 days	Tue 9/20/11	Tue 9/27/11
10	Design Scheme Memo (60% of Design)	5 days	Tue 9/27/11	Mon 10/3/11
11	D80 Presentations	5 days	Tue 9/27/11	Mon 10/3/11
12	Reports, Posters, and Oral Presentation (D80)	10 days	Tue 9/27/11	Sat 10/8/11
13	Status Report #2	5 days	Tue 10/11/11	Mon 10/17/11
14	Status Report #3	5 days	Tue 10/18/11	Mon 10/24/11
15	Cost Estimate and Schedule	15 days	Tue 10/18/11	Mon 11/7/11
16	Status Report #4	10 days	Tue 10/25/11	Mon 11/7/11
17	Draft Final Report	5 days	Tue 11/8/11	Mon 11/14/11
18	Draft Poster	10 days	Tue 11/15/11	Mon 11/28/11
19	Final Project Presentations	6 days	Tue 11/29/11	Tue 12/6/11
20	Final Information (Due @ Noon)	3 days	Wed 12/7/11	Fri 12/9/11
21	**Mechanical Engineering**	**64 days**	**Tue 9/13/11**	**Fri 12/9/11**
22	Turbine Selection	11 days	Tue 9/6/11	Tue 9/20/11
23	Mechanical 3D Modeling	26 days	Tue 9/27/11	Tue 11/1/11
24	Finite Element Analysis	10 days	Tue 11/1/11	Mon 11/14/11
25	**Electrical Engineering**	**69 days**	**Tue 9/6/11**	**Fri 12/9/11**
26	Generator and Turbine Design	11 days	Tue 9/13/11	Tue 9/27/11
27	Energy Analysis	26 days	Tue 9/13/11	Tue 10/18/11
28	Power Electronics	16 days	Tue 10/18/11	Tue 11/8/11
29	Energy Distribution	46 days	Tue 9/13/11	Tue 11/15/11
30	**Civil Engineering**	**69 days**	**Tue 9/6/11**	**Fri 12/9/11**
31	Flow Rate Analysis	6 days	Tue 9/6/11	Tue 9/13/11
32	Penstock Design	7 days	Mon 9/19/11	Tue 9/27/11
33	Site Planning	6 days	Tue 9/20/11	Tue 9/27/11
34	Stream Flow Modeling	21 days	Tue 9/20/11	Tue 10/18/11
35	Watershed Deliniation	3 days	Sun 10/30/11	Tue 11/1/11
36	Site Modeling	35 days	Tue 9/27/11	Mon 11/14/11



Project: Course Schedule Finish So
Date: Thu 9/15/11

Task		Project Summary		Inactive Milestone		Manual Summary Rollup		Deadline	
Split		External Tasks		Inactive Summary		Manual Summary		Progress	
Milestone		External Milestone		Manual Task		Start-only			
Summary		Inactive Task		Duration-only		Finish-only			

Course Schedule Finish Sorted 2.mpp

Figure 13: Design Schedule

Appendix F: Inlet Details

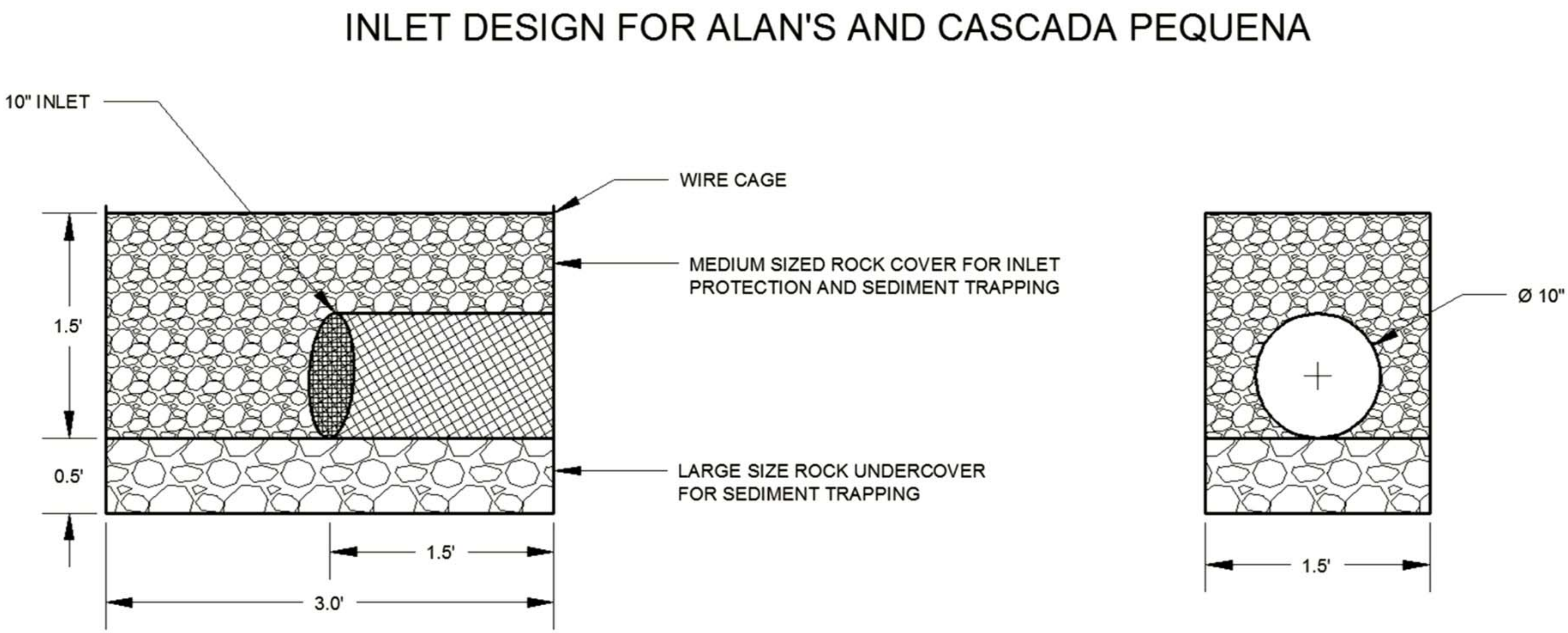


Figure 14: Inlet Design

Appendix G: Cascada Pequeña with Trench

Potential Power

Table 18: Cascada Pequeña Penstock

Ho (ft)	L (ft)	f (ft/ft)	Q (ft3/s)	D1 (ft)	A1 (ft2)	V1 (ft/s)	Ki	ε	D2 (ft)	A2	Ht (ft)	Power (kW)	Δ kW
30	210	0.01	2.00	0.83	0.55	3.67	0.5	0.55	3.00	7.07	29.37	**2.75**	--
30	210	0.01	2.50	0.83	0.55	4.58	0.5	0.55	3.00	7.07	29.01	**3.39**	0.65
30	210	0.01	3.00	0.83	0.55	5.50	0.5	0.55	3.00	7.07	28.58	**4.01**	0.62
30	210	0.01	3.50	0.83	0.55	6.42	0.5	0.55	3.00	7.07	28.07	**4.59**	0.58
30	210	0.01	4.00	0.83	0.55	7.33	0.5	0.55	3.00	7.07	27.47	**5.14**	0.55
30	210	0.01	4.50	0.83	0.55	8.25	0.5	0.55	3.00	7.07	26.80	**5.64**	0.50
30	210	0.01	5.00	0.83	0.55	9.17	0.5	0.55	3.00	7.07	26.05	**6.09**	0.45
30	210	0.01	5.50	0.83	0.55	10.08	0.5	0.55	3.00	7.07	25.22	**6.49**	0.40
30	210	0.01	6.00	0.83	0.55	11.00	0.5	0.55	3.00	7.07	24.31	**6.82**	0.34
30	210	0.01	6.50	0.83	0.55	11.92	0.5	0.55	3.00	7.07	23.33	**7.09**	0.27
30	210	0.01	7.00	0.83	0.55	12.83	0.5	0.55	3.00	7.07	22.26	**7.29**	0.20
30	210	0.01	7.50	0.83	0.55	13.75	0.5	0.55	3.00	7.07	21.12	**7.41**	0.12
30	210	0.01	8.00	0.83	0.55	14.67	0.5	0.55	3.00	7.07	19.89	**7.44**	0.04
30	210	0.01	8.50	0.83	0.55	15.58	0.5	0.55	3.00	7.07	18.59	**7.39**	-0.05
30	210	0.01	9.00	0.83	0.55	16.50	0.5	0.55	3.00	7.07	17.21	**7.24**	-0.15
30	210	0.01	9.50	0.83	0.55	17.42	0.5	0.55	3.00	7.07	15.74	**7.00**	-0.25
30	210	0.01	10.00	0.83	0.55	18.33	0.5	0.55	3.00	7.07	14.20	**6.64**	-0.35
30	210	0.01	10.50	0.83	0.55	19.25	0.5	0.55	3.00	7.07	12.59	**6.18**	-0.46

A pipe with a 10” diameter will restrict the potential power at this site, but a larger pipe is not practical. The last column (ΔkW) measures the increase in power from differing flow rates.

Power Canal Design

Use Manning's Equation to find the velocity in the pipe and channel.

Flow in pipe:
Assume:

- $n_{PVC} = 0.009 - .011$
  (http://www.lmnoeng.com/manningn.htm)
- $n_{Earth} = 0.025$
  (http://www.lmnoeng.com/manningn.htm)
- $V_{Max(Bare\ Firm\ Clay\ Loam\ Soil)} = 3.5\frac{ft}{s}$
  (http://age-web.age.uiuc.edu/classes/age357/html/age35719.pdf)
- $\alpha = 1.0$

Flow Rate in Pipe to Canal (fps):

$Q = \frac{Cm}{n} A \left(\frac{A}{R_h}\right)^{\frac{2}{3}} S_o^{0.5}$, Manning's Equations

$$A = \left(\frac{\pi * \left(\frac{10}{12}\right)^2}{4}\right) = 0.5454 ft^2\ (0.051 m^2)$$

$$R_h = \frac{D}{4} = \frac{\frac{10}{12}}{4} = 0.21 ft\ (0.064\ m)$$

$$S_o = 0.01$$

$$Q = \frac{Cm}{n} A \left(\frac{A}{R_h}\right)^{\frac{2}{3}} S_o^{0.5} = \frac{1.49}{0.01} * 0.5454 * \left(\frac{0.5454}{0.21}\right)^{\frac{2}{3}} * 0.005^{0.5} = \mathbf{10.9\ cfs\ (308.7\ lps)}$$

One 10" pipe at a slope of .005 will provide 308.7 lps.

Flow Rate in Canal to Settling Basin:

$$Flow\ Rate\ in\ Canal\ (fps) = Q_{TotalPipe}(fps) = 10.9\ cfs\ (308.7\ lps)$$

Flow Rate in Penstock Pipe:

$S_o = 0.138$, see section in Appendix L titled penstock geometry for bases behind this value.

$8(cfs) = \frac{Cm}{n} A \left(\frac{A}{R_h}\right)^{\frac{2}{3}} S_o^{0.5} = \frac{1.49}{0.01} * A * \left(\frac{A}{0.21}\right)^{\frac{2}{3}} * 0.138^{0.5}$, Solve for A=Pipe Area (ft^2).

$$A = 0.1678\ ft^2$$

$0.1678\ ft^2 = \left(\frac{\pi * \left(\frac{D}{12}\right)^2}{4}\right)$, Solve for D=Diameter of Pipe (ft)

$$D = 0.4623\ ft$$

$$D = 0.4623 * 12 = 5.55 in.$$

$\therefore \boldsymbol{Diameter\ of\ Penstock\ \geq 6.0 in}.$

When $A = 6.0 in$:

$$Q(cfs) = \frac{Cm}{n} A \left(\frac{A}{R_h}\right)^{\frac{2}{3}} S_o^{0.5} = \frac{1.49}{0.01} * 0.1678 * \left(\frac{0.1678}{0.21}\right)^{\frac{2}{3}} * 0.138^{0.5} = 8.0\ cfs\ (227\ lps)$$

Cross-Section Power Canal Design: (http://age-web.age.uiuc.edu/classes/age357/html/age35719.pdf)
For $Q = 10.9\ cfs$ and Maximum Velocity for Firm clay loam 3.5 ft/s (1.07 m/s)
[Source for max velocity, http://age-web.age.uiuc.edu/classes/age357/html/age35719.pdf]

Use a conservative value for the velocity of $V = 2.0 \frac{ft}{s}$

$$A = \frac{Q}{V} = \frac{10.9\frac{ft^3}{s}}{2.0\frac{ft}{s}} = 5.5\ ft^2\ (0.51\ m^2)$$

Trapezoidal trench recommended $\therefore Area = y(b + my)$

Canal Design (English Units)			
Depth, y (ft)	Bottom Width, b (ft)	SS, m	y(b+my) (ft)
0.74	6	2	5.5
0.83	5	2	5.5
0.94	4	2	5.5
1.07	3	2	5.5
0.68	6	3	5.5
0.76	5	3	5.5
0.84	4	3	5.5
0.94	3	3	5.5

Canal Design (SI Units)			
Depth, y (m)	Bottom Width, b (m)	SS, m	y(b+my) (m)
0.22	1.8	2	0.51
0.25	1.5	2	0.51
0.29	1.2	2	0.51
0.33	0.9	2	0.51
0.21	1.8	3	0.51
0.23	1.5	3	0.51
0.26	1.2	3	0.51
0.29	0.9	3	0.51

All of the above rows will be adequate for the canal design. Using a side slope (SS) of three will be more stable and therefore is recommended. The values in the table are the minimum values that could be used for a canal design. The depths and width can be increase, but not decreased.

Settling Basin for Cascada Pequeña's Canal

Location:

The Location of the settling basin is at the end of the trench at Cascada Pequeña.

Purpose:

The purpose of a settling basin is to remove sediment particles suspended in water. This is done by slowing moving water down into a large pool or basin large enough to give the suspended particles adequate time to sink to the bottom of the basin.

Components:

Size of Settling Basin

Depth of Basin (constant depth, requires a weir.)

Cross-Sectional Area

Size of the basin dependent on:

Flow

Velocity Entering Basin

Particle size

Amount of suspended solids

Design Procedure: (Barkdoll and Watkins 2009)

$LW = \frac{E_t Q}{V_s}$, (Equation 10.13)

$E_t = Trap\ Efficiency$

$V_s\left(\frac{ft}{s}\right) = \frac{D^2(\gamma_s - \gamma_{water})}{18\mu} = \frac{D^2\left(\gamma_s - \frac{62.4lbs}{ft^3}\right)}{18*\left(2.5*10^{-5}\left(lb - \frac{s}{ft^2}\right)\right)} = Settling\ Velocity$, (Stokes Law)

$D(ft) = Diameter\ of\ Average\ Soil\ Partical$

$\gamma_s\left(\frac{lbs}{ft^3}\right) = Unit\ Weight\ of\ Soil$

$E_t = \frac{V_s}{\frac{Q}{A}} = \frac{L}{H}\left(\frac{V_s}{V_x}\right)$, (Equation 10.8),

$Q\left(\frac{ft^3}{s}\right) = Flow\ Rate\ Into\ Basin$

$A(ft^2) = Bottom\ Surface\ of\ Sediment\ Basin$

$L(ft) = Horizontal\ Length\ of\ Basin$

$W(ft) = width\ of\ Basin$

$H(ft) = Average\ depth$

$V_x = \frac{Q}{A_{cx}}$,(Equation 10.9)

$A_{cx}(ft^2) = 0.5\pi x^2 (tan15°)^2$, (Equation 10.11)

$x(ft) = Distance\ From\ Inlet$

$A_j(ft^2) = 2\left(\frac{1}{2xr}\right) = x^2 \tan(15°) = Projected\ Area$, (Equation 10.12)

Design Calculations:

Known:

$Q_{Trench}\left(\frac{ft^3}{s}\right) = 8.0\ cfs\ (227\ lps)$

$E_t = 0.95$

$V_s = \frac{D^2(\gamma_S - \gamma_{water})}{18\mu} = \frac{0.000246^2\left(130\frac{lbs}{ft^3} - \frac{62.4lbs}{ft^3}\right)}{18*\left(2.5*10^{-5}\left(lb - \frac{s}{ft^2}\right)\right)} = 0.0091\frac{ft}{s}\ \left(0.0028\frac{m}{s}\right)$

$D = 0.000246ft$, Table 10.8 (Barkdoll and Watkins 2009)pg.53

$\gamma_s(Unsaturated) = 65\frac{lbs}{ft^3}\ (1041\frac{kg}{m^3}) \therefore \gamma_s(Saturated) = 65 + 65 = 130\frac{lbs}{ft^3}\ \ (2082\frac{kg}{m^3})$, Table 10.2: Specific Weight $\gamma_s$of Submerged Soils, pg 139

$LW = \frac{E_t Q}{V_s} =. \frac{0.95\left(\frac{8.0ft^3}{s}\right)}{0.0091\left(\frac{ft}{s}\right)} = 835.2ft^2\ (77.6\ m^2)$

Recommended Design:

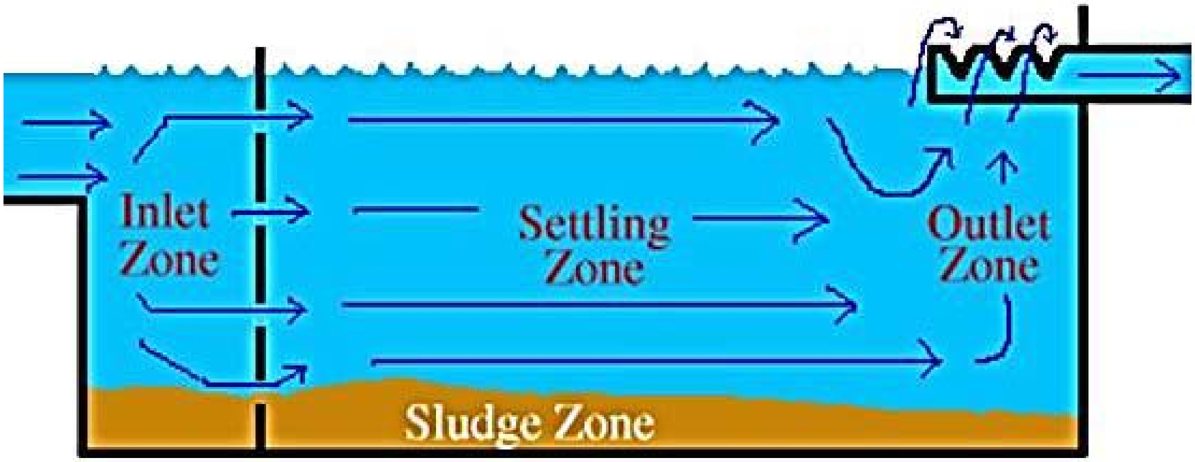
$Length = Width \cong 29ft\ (8.84\ m)$

$Depth = 4ft\ (1.22\ m)$

Recommended Maintenance:

Clean when the water depth has diminished to approximately two feet.

Example:



http://water.me.vccs.edu/courses/env110/Lesson14_print.htm

http://www.svid.org/settling_basins.htm

Recommended Path for Canal and Penstock Location

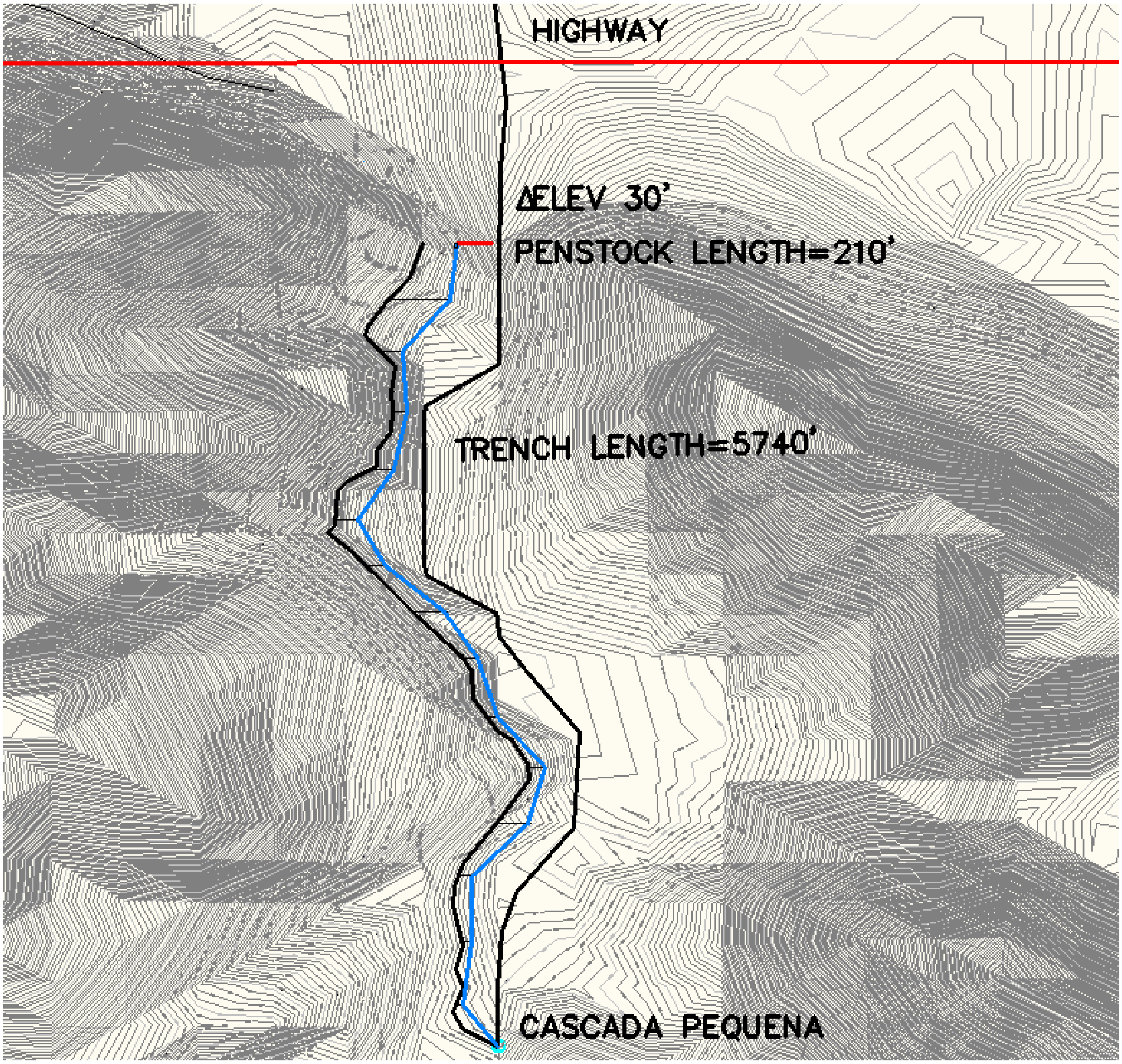


Figure 15: Recommended Trench Path for Cascada Pequeña with Power Canal

This image is an example of the power canal mentioned in the report. The bold black line on the left is a contour line at an elevation of 109.7m (360 ft.). The bold blue line is a potential path for the power canal. This line drops down a two foot contour line; the contour lines are represented by the fine lines, about every 115.8m (380 ft.). The bold fine lines that cross from the109.7m (360 ft.) line to the blue power canal line represent the locations of this designated drop. The reason for this drop is to keep the water flowing downhill.

The short red line represents the recommended placement of the penstock. This line also represents a changed in elevation of 9.1m (30 ft.). There for this site has a potential head of 9.1m (30 ft.). Lastly, the bold black line on the right represents the river and the long red line that runs a crossed the top represents the road.

System Layout

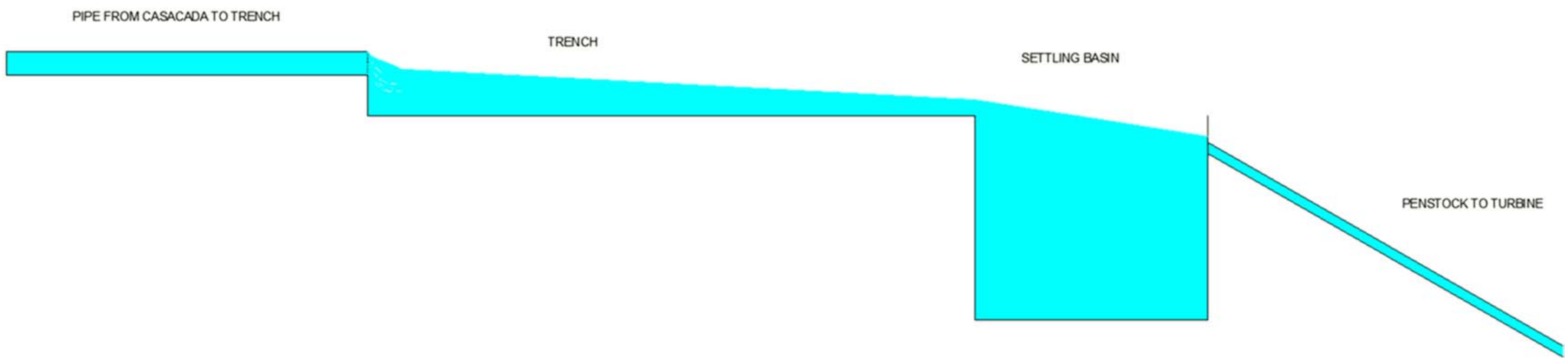
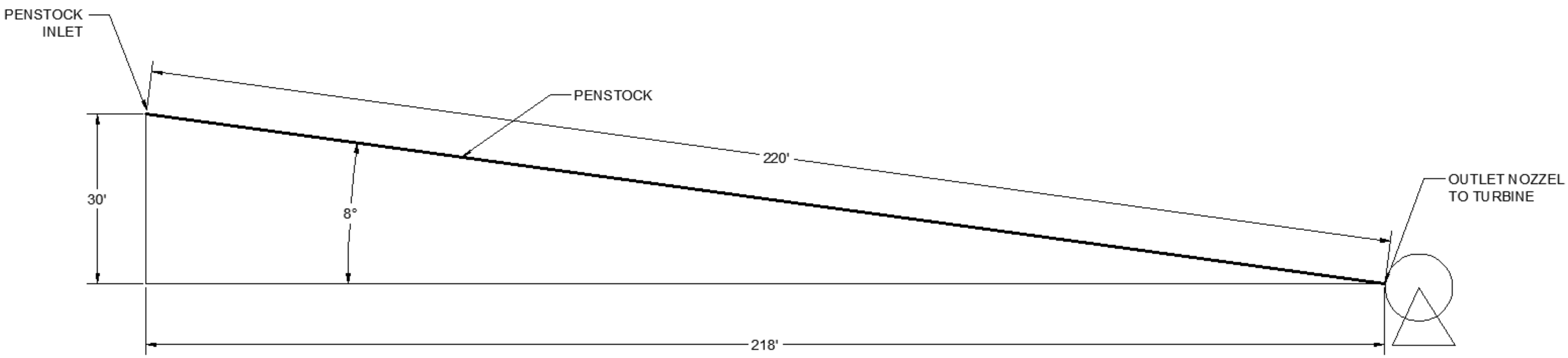


Figure 16: Cascada with Trench Water System Layout

Penstock Geometry

CASCADA PEQUENA PENSTOCK GEOMETRY



Appendix H: Work Breakdown Structure and Schedule for Construction

General Construction

Acquire Materials

1.0 Commence Construction
- 1.1 Arranging community work schedule
- 1.2 Begin acquiring materials

2.0 Acquire high demand supplies
- 2.1 Penstock Supplies
  - 2.1.1 800 feet of 10” PVC pipe
  - 2.1.2 Gate Valve
  - 2.1.3 Cleaner and Adhesive Agent
  - 2.1.4 Aggregate, Sand, and Cement for thrust blocks
  - 2.1.5 Wood or metal poles for supports
- 2.2 Inlet Supplies
  - 2.2.1 Stainless Steel Wire mesh
  - 2.2.2 Wire clippers
  - 2.2.3 River rocks and gravel
  - 2.2.4 Stainless Steel Wire for forming cage
- 2.3 Foundation Supplies
  - 2.3.1 Wood for forms
  - 2.3.2 Aggregate, Sand, and Cement
  - 2.3.3 Shovel for clearing
- 2.4 Turbine Supplies
  - 2.4.1 30'x1" Dia. Steel Bars
  - 2.4.2 2-3'x3'x1/2" Stainless Steel plates
  - 2.4.3 14'x1' Dia. Stainless Steel Pipe-1/2" Thick
  - 2.4.4 6'x3" Dia. Stainless Steel Rod
  - 2.4.5 2' Dia. Steel Disc 6" Thick (Weld)
  - 2.4.6 Belt (from output shaft to generator)
  - 2.4.7 4-2"x2"x1/4" Stainless Steel Plates
  - 2.4.8 4-Large Stainless Steel bolts
  - 2.4.9 6'x6' Aluminum Sheet
  - 2.4.10 Generator
  - 2.4.11 Welder

3.0 Acquire medium demand supplies
- 3.1 Generator supplies
  - 3.1.1 Motor
  - 3.1.2 Belt
- 3.2 Outlet Supplies

3.2.1 10” PVC Length
3.2.2 Stainless Steel Metal Pipe
3.2.3 Stainless Steel Metal Plate

4.0 Acquire low demand supplies
  4.1 Transformer and power electronics
  4.2 Power poles
  4.3 Transmission lines
  4.4 Electrical supplies for homes
    4.4.1 Copper lines
    4.4.2 Electrical boxes
    4.4.3 Fuses
    4.4.4 Outlets
    4.4.5 Transformers

Final Inspection

5.0 Project engineer investigates all aspect of the project with community leaders and construction manager
  5.1 Identify punch list (check list) items
  5.2 Address problems or current concerns
  5.3 Conclude project when all is well

Civil Construction

6.0 Carry in penstock supplies

7.0 Mark penstock route
  7.1 Go to the Alan’s Falls and analyze the best path for the penstock.
    7.1.1 See recommendations for penstock path in Appendix # of the report.
    7.1.2 Make on site changes as the topography of the falls requires.
  7.2 Make a sketch of the surrounding area with the most ideal penstock path based on site conditions.
  7.3 Select a location for foundation, see site recommendation in Appendix #

8.0 Construct hydraulic barrier
  8.1 Arrange large rocks near the top of the rock ridge such that the height of the water rises in the pool where the inlet structure will be placed
  8.2 Direct water with large rocks such that the flow of water is guided to the inlet structure.

9.0 Construct inlet and outlet
  9.1 See an example of the inlet structure in Appendix J: Inlet Details of the report
    9.1.1 Gather rocks approximately 2-3 inches in diameter for the large rocks and rocks approximately 0.5-2 inches in diameter for the medium size rocks
    9.1.2 Form wire mesh into a 1’ wide x 2’ high x 3’ long cage
    9.1.3 Cut a 10” whole on one of the 1’ x 2’ sides about 6” from the bottom
    9.1.4 Cover the bottom of the cage with large rocks up to the invert of the whole

9.1.5 Place PVC pipe about half way into cage
9.1.6 Fill cage the rest of the way with medium stones
9.2 See an example of the outlet structure in Appendix K: Outlet Details of the report
9.2.1 Modify 10”PVC pipe with extra metal from the construction of the turbine
10.0 Layout penstock
10.1 Distrusted Lengths of penstock along the route previously sketched for the penstock path
10.2 Make sure all connections are unharmed
10.3 Be sure to mark locations the need supports
11.0 Construct supports
11.1 Form wooden or metal stands for penstock to sit on.
11.2 In low spots be sure to have supports built in order to keep the pipe strong and sloping downward.
11.3 Construct a strong support for the outlet of the penstock so that it will not shake from the water pressure at the outlet.
12.0 Construct penstock
12.1 Begin putting the penstock that has been laid out together. Start at the inlet and move to the outlet.
12.2 While joining lengths place adhesive in the joints
12.2.1 Coat the male end on the outside and female end on the inside
12.2.2 Move the joint as little as possible after the adhesive has been applied otherwise it will not adhere correctly.
12.3 While low spots or long flat spots are being crossed, place supports at joints in order to keep the pipe strong and sloping downward.
12.4 Secure penstock to supports
12.5 Place modified PVC pipe at the outlet.
12.5.1 Outlet should be placed such that water sprays up and down
12.5.2 Be sure to strongly fasten the outlet to the strong outlet support.
13.0 Review constructed penstock
13.1 Check connections for leaks
13.2 Check valves for functionality
13.3 Check that all supports and steady and are securely fasted to penstock
13.4 Downward sloping
13.5 Make sure all of the water from the penstock outlet is hitting the upper half of the turbine.

Foundation

14.0 Bring in aggregate and cement for foundation
15.0 Prepare base for generator house
16.0 Haul in wood for forms
17.0 Build wooden forms
18.0 Pour concrete for generator house
19.0 Foundation Curing Time

19.1 Let the concrete set up for one week before placing any weight on it
19.2 Remove wooden forms after the one week curing period
20.0 Build Generator house
20.1 Create a structure over the turbine and generator that will keep debris from interfering with rotation

Mechanical Construction

21.0 Cut 30'x1" Dia. Steel Bars
22.0 Construct Wheel
23.0 Construct Base
24.0 Move Constructed Turbine to Alan's Falls
24.1 Haul tools to install the turbine to the site.
25.0 Install Turbine on Concrete Slab
26.0 Adjust penstock nozzles to turbine
26.1 Open Gate Valve located at the penstock inlet to allow water to flow.
26.2 Position the nozzles at the outlet of the penstock so that it hits the upper half of the turbine in such a way that creates most rotations per minute as possible.
27.0 Connect Turbine to Generator

Electrical Construction

Generation

28.0 Purchase Motor to be Used as Generator
28.1 Generator specifications of 15 kVA, 3 phase induction motor, 230/460V output
29.0 Send Motor Out to be Modified
30.0 Generator Winding Fix and Capacitor Bank Addition
31.0 Haul Generator to Site
32.0 Mount Generator to Foundation
32.1 Drill into concrete with in the pattern on the generator housing
32.2 Bolt the frame of the generator to the concrete
33.0 Fit Turbine to Generator With Appropriate Gear
34.0 Haul in Transformer and Power Electronics
34.1 Build Electronics Panel
34.1.1 Mount a utility box on the wall of the Generator housing
34.1.2 Mount the IGC in the box
34.1.3 Mount the ballast loads to wall (far away from the IGC, as these will heat up)
34.1.4 Mount the Ground fault breaker on the wall near the IGC.
34.1.5 Mount another Utility Box for the main breaker switch.
34.1.5.1 Install main breaker switch in this box
35.0 Wire Generator to Ballast Loads and IGC
35.1 There will be 4 wires coming out of the generator: Hot, Neutral, 2C, and ground

35.2 Wire the hot, neutral, and 2C wires to the motor protection breaker on the IGC

35.3 Run wire from the hot to the 2C capacitor, the 2C line to the C capacitor, and neutral to both capacitors.

35.4 From the IGC output, attach the hot and neutral to the ballast load(s)

35.5 Attach the ground wire to a rebar spike and place in the ground.

36.0 Tie in the Ground Fault Breaker

36.1 From the IGC output, attach the hot and neutral to the Ground Fault Breaker

37.0 Install Main Breaker

37.1 From the Ground Fault Breaker, wire the hot and neutral wires to the Main Breaker

38.0 Install Step Up Transformer

38.1 From the main breaker, run the hot and neutral wires to the low side of the step up transformer (should be labeled with an 'X', whereas the high side will be labeled with an 'H')

Transmission

39.0 Layout path of transmission line

39.1 Mark a route from the generator site to the village for transmission lines

39.2 Sketch rough estimate of route and identify pole locations

40.0 Clear right-of-way

40.1 Clear trees to the right and left of path, clearing 20 feet on either side of path's centerline.

40.2 Be careful not to leave large rotten trees or leaning trees near this path.

41.0 Dig Holes for Transmission Poles

41.1 Must be at least 2 feet deep to make sure they don't tip over

42.0 Haul Poles to Specific Locations

43.0 Install Poles

43.1 Fill holes with concrete or stone of similar size (e.g. all 1" stone) once the poles are up

44.0 Roll Out Transmission Lines to Specific Locations

45.0 Run Lines

45.1 Mount tie wire

45.2 Mount ceramic insulators

45.3 Splice Lines (as needed)

Distribution

46.0 Distribute Copper Lines, Electrical Boxes, Fusses and Outlets

47.0 Install Step Down Transformer for Village Distribution

47.1 Connect the hot and neutral wires from the transmission to the high side (H) of the step-down transformer.

47.2 Connect the hot and neutral wires of the in-village transmission lines to the low side (X) of the transformer.

48.0 Run Transmission Lines for In-village Distribution

48.1 Staple Tie Wire to Poles

48.2 Run ceramic insulators through the transmission line

48.3 Mount the insulator enclosing the transmission line to the pole with tie wire.

49.0 Install Step Down Transformers

49.1 Hang 1 kVA – 2 kVA transformers on poles.

49.2 Wire hot and neutral wire from transmission line to high side of transformer

49.3 Wire (copper) hot and neutral wire from low side of transformer to the utility box.

50.0 Wire Each Home

50.1 Install Utility boxes for each home

50.1.1 Install fuse holder in the box and connect between the hot wire from transformer to hot wire going into the house.

50.2 Install Fuses for each home

50.3 Install electrical outlets

50.4 Run hot and neutral from utility box to each outlet.

50.5 Run ground line from the enclosure to the ground with a rebar spike.

ID		Task Name	Duration	Start	Finish	Predecesso
1						
2		**General Construction**				
3		Commence Construction	3 days	Wed 8/1/12	Fri 8/3/12	
4		Acquire High Demand Supplies	14 days	Mon 8/6/12	Thu 8/23/12	3
5		Acquire Medium Demand Supplies	14 days	Mon 8/6/12	Thu 8/23/12	3
6		Acquire Low Demand Supplies	14 days	Mon 8/6/12	Thu 8/23/12	3
7		Final Inspection	3 days	Tue 12/25/12	Fri 12/28/12	62,56,48
8						
9		**Civil Construction**				
10		Carry In Penstock Supplies	6 days	Fri 8/24/12	Fri 8/31/12	4
11		Mark Penstock Route	1 day	Mon 9/3/12	Mon 9/3/12	10
12		Construct Hydraulic Barrier	1 day	Mon 8/6/12	Mon 8/6/12	3
13		Construct Inlet	2 days	Mon 9/3/12	Tue 9/4/12	12,10
14		Layout Penstock	1 day	Mon 9/3/12	Mon 9/3/12	10
15		Construct Supports	1 day	Tue 9/4/12	Tue 9/4/12	14
16		Construct Penstock	1 day	Tue 9/4/12	Tue 9/4/12	14
17		Review Constructed Penstock	1 day	Wed 9/5/12	Wed 9/5/12	16
18		**Foundation**				
19		Bring in Aggregate and Cement for Foundation	6 days	Fri 8/24/12	Fri 8/31/12	4
20		Prepare Base for Generator house	1 day	Wed 9/5/12	Wed 9/5/12	19,16
21		Haul in Wood for Forms	1 day	Mon 9/3/12	Mon 9/3/12	4,19
22		Build wooden forms	1 day	Tue 9/4/12	Tue 9/4/12	21
23		Pour concrete for generator house	2 days	Thu 9/6/12	Fri 9/7/12	22,20
24		Foundation Curing Time	7 days	Fri 9/7/12	Mon 9/10/12	23
25		Build Generator house	2 days	Mon 9/10/12	Tue 9/11/12	24
26						
27		**Mechanical Construction**				
28		Cut 30'x1" Dia. Steel Bars	2 days	Fri 8/24/12	Mon 8/27/12	4
29		Construct Wheel	7 days	Tue 8/28/12	Wed 9/5/12	28
30		Construct Base	4 days	Fri 8/31/12	Wed 9/5/12	29FF
31		Move Constructed Turbine to Alan's Falls	1 day	Thu 9/6/12	Thu 9/6/12	30
32		Install Turbine on Concrete Slab	1 day	Mon 9/10/12	Mon 9/10/12	24,31
33		Adjust Penstock Nozzles to Turbine	1 day	Tue 9/11/12	Tue 9/11/12	17,32
34		Connect Turbine to Generator	1 day	Tue 9/11/12	Tue 9/11/12	32
35						
36		**Electrical Construction**				
37		**Generation**				
38		Purchase Motor to be Used as Generator	7 days	Fri 8/24/12	Mon 9/3/12	5
39		Send Motor Out to be Modified	4 days	Tue 9/4/12	Fri 9/7/12	38
40		Generator Winding Fix and Capacitor Bank Addition	35 days	Mon 9/10/12	Fri 10/26/12	39
41		Haul Generator to Site	1 day	/lon 10/29/12	/lon 10/29/12	39,40
42		Mount Generator to Foundation	1 day	Tue 10/30/12	Tue 10/30/12	41,24
43		Fit Turbine to Generator With Appropriate Gear	2 days	Ved 10/31/12	Thu 11/1/12	42,34
44		Haul in Transformer and Power Electronics	1 day	Fri 11/2/12	Fri 11/2/12	6,43
45		Wire Generator to Ballast Loads and IGC	3 days	Mon 11/5/12	Wed 11/7/12	44
46		Tie in the Ground Fault Breaker	2 days	Thu 11/8/12	Fri 11/9/12	45
47		Install Main Breaker	1 day	/lon 11/12/12	/lon 11/12/12	46
48		Install Step Up Transformer	1 day	Tue 11/13/12	Tue 11/13/12	47
49		**Transmission**				
50		Layout Path of Transmition Line	5 days	Mon 8/6/12	Fri 8/10/12	3
51		Clear Right-of-Way	30 days	Mon 8/13/12	Fri 9/21/12	50
52		Dig Holes for Transmission Poles	40 days	Mon 8/27/12	Fri 10/19/12	51SS+10 d
53		Haul Poles to Specific Locations	24 days	Tue 9/18/12	Fri 10/19/12	6,52FF
54		Install Poles	30 days	Thu 9/20/12	Ved 10/31/12	6,53SS+2 d
55		Roll Out Transmission Lines to Specific Locations	25 days	Tue 10/2/12	Mon 11/5/12	54FF+3 da
56		Run Lines	21 days	Mon 10/8/12	Mon 11/5/12	55FF
57		**Distribution**				
58		Distribute Copper Lines, Electrical Boxes, Fuses and Outl	18 days	Sat 10/20/12	Tue 11/13/12	6
59		Install Step Down Transformer for Village Distribution	2 days	Tue 11/13/12	Thu 11/15/12	58
60		Run Transmission Lines for In-village Distribution	14 days	Thu 11/15/12	Wed 12/5/12	59
61		Install Step Down Transformers	14 days	Thu 11/15/12	Wed 12/5/12	60SS
62		Wire Each Home	28 days	Thu 11/15/12	Tue 12/25/12	61SS
63						

Project: Hydro Project Schedule1.
Date: Fri 11/4/11

Task	Summary	External Milestone	Inactive Summary	Manual Summary Rollup	Finish-only
Split	Project Summary	Inactive Task	Manual Task	Manual Summary	Deadline
Milestone	External Tasks	Inactive Milestone	Duration-only	Start-only	Progress

Figure 17: Construction Design Schedule

Appendix I: Transmission, Distribution, and Metering Diagrams

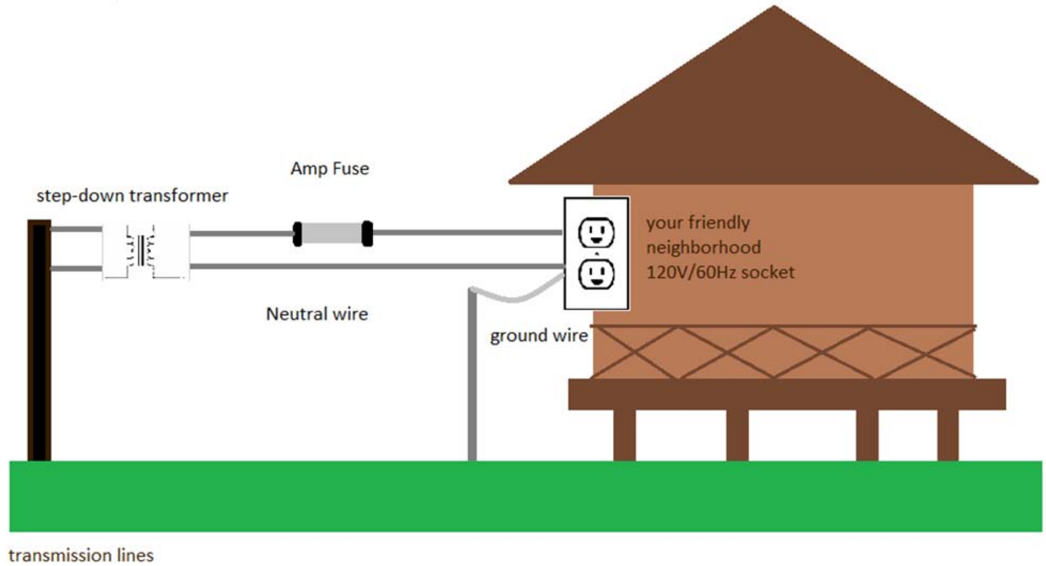


Figure 18: Transmission, Distribution, and Metering

Figure 18 is a sketch showing the generalized distribution system, including the amp fuse that will act as a meter for households and prevent overdrawing of the power system.

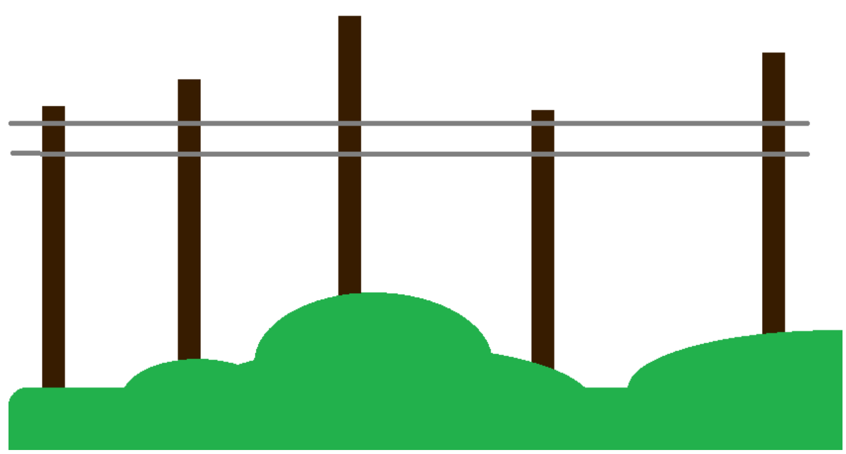
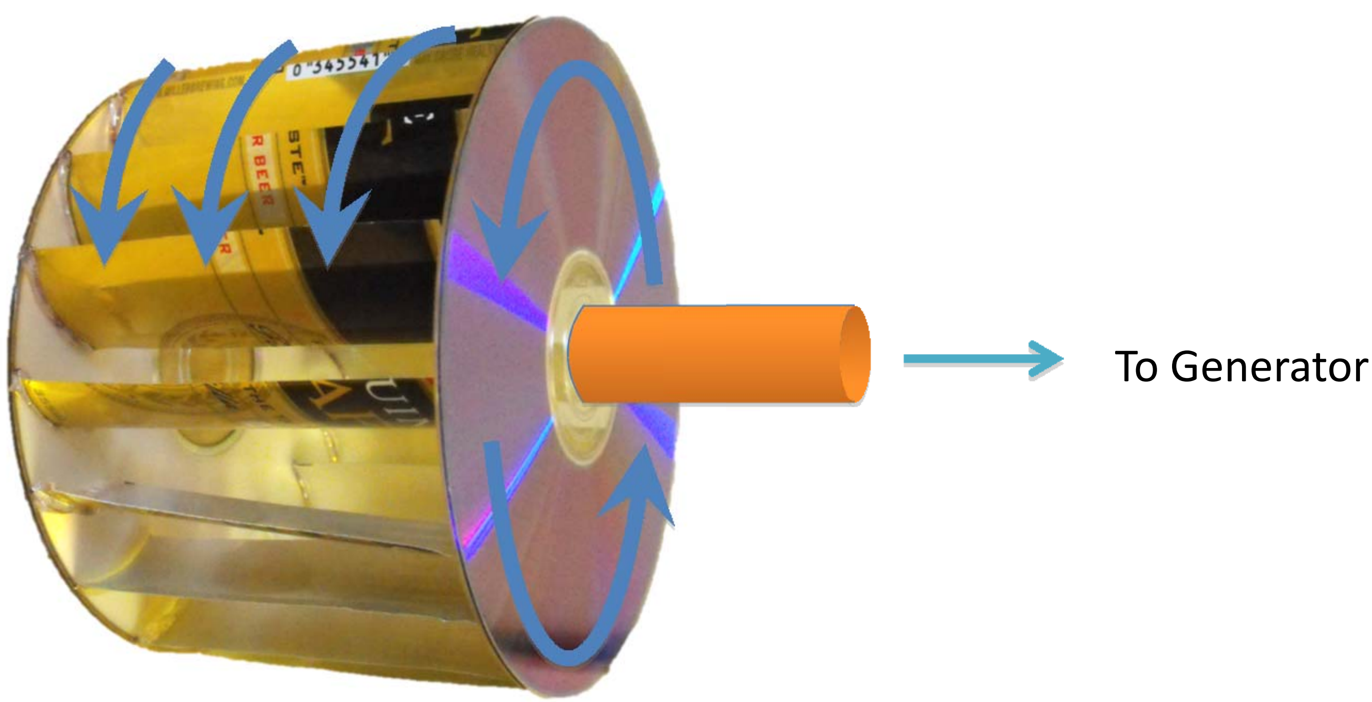


Figure 19: Transmission Wiring

Transmission wiring should prioritize the stabilization of line evenness over ground clearance. In some instances of inclines or grades, wire placement may not be on the same section of the pole; however, it is important to keep the lines relatively straight through the length of transmission. It is noted that up to a 5 foot change in height is acceptable between spans under 150 feet, and a 10 foot change is acceptable between spans of 150 feet and 300 feet. Spans above 300 feet are not recommended for this system. The distribution system will priority ground clearance as it will be easier to control grade in inhabited areas.

Appendix J: Turbine Prototype

Figure 20: Turbine Prototype



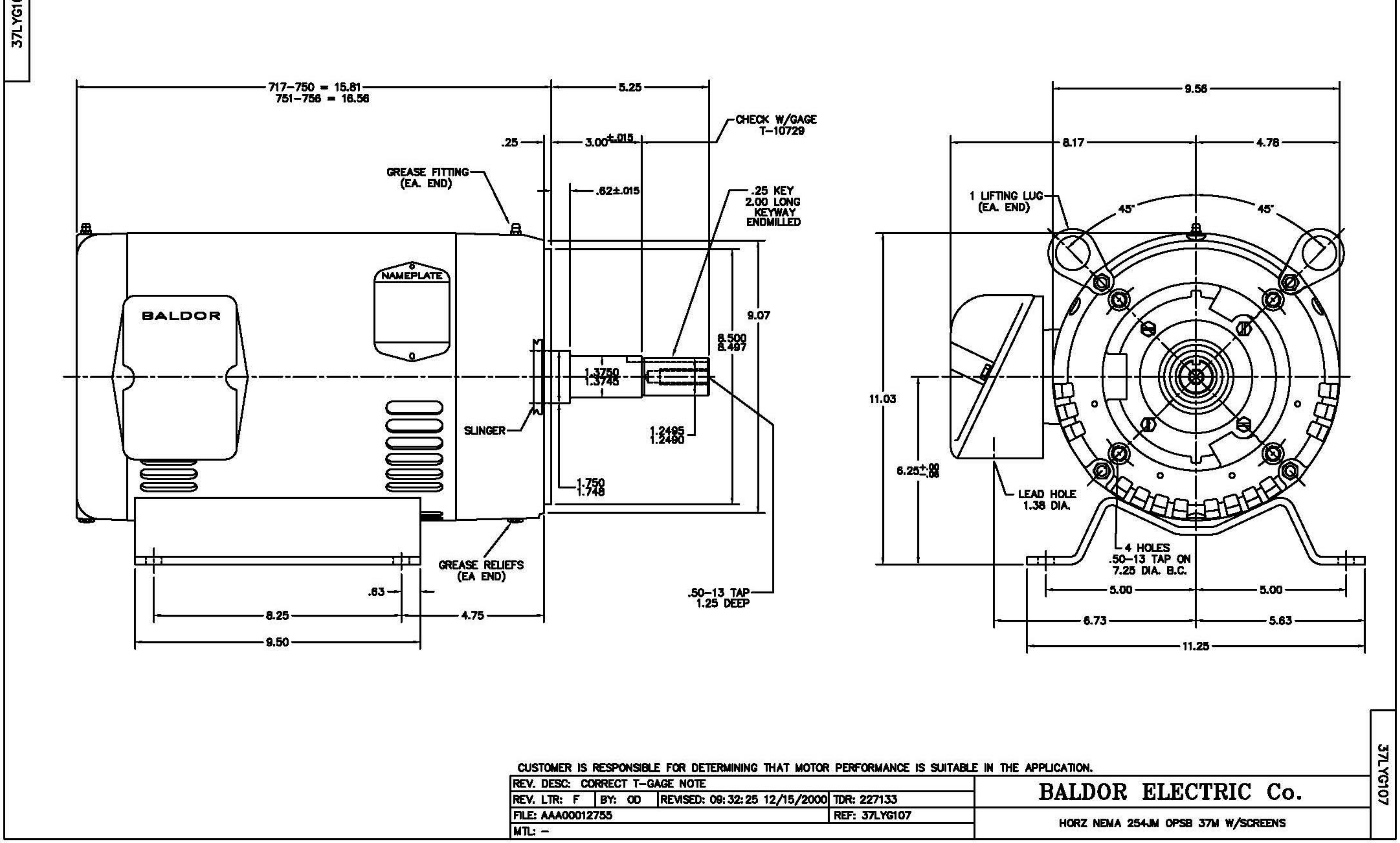
Appendix K: Motor Specifications

Product Nameplate Data :					
Rated Output	15 HP	Hertz	60	NEMA Nom. Eff.	91
Volts	208-230/460	Phase	3	Power Factor	81
Full Load Amps	41-38/19	NEMA Design Code	A	Service Factor	1.15
Speed	1760	LR KVA Code	J	Rating - Duty	40C AMB-CONT

General Characterstics at 460 V, 60 Hz, 20 HP			
Full Load Torque	44.67 LB-FT	Starting Current	135.7 Amps
Start Configuration	DOL	No-Load Current	8.45 Amps
Break Down Torque	187.4 LB-FT	Line-line Resistance @ 25° C	0.695 Ohms
Pull-Up Torque	63.3 LB-FT	Temperature Rise, C @ FL (in deg)	54
Locked-Roter Torque	90.4 LB-FT	Temp. Rise @ S.F. Load (in deg)	64

Load Characteristics at 460 V, 60 Hz , 20 HP							
% of Rated Load	25	50	75	100	125	150	S.F.
Power Factor	42	64	75	81	83	83	82
Efficiency	86.4	9038	91.5	91	90	88.6	90.4
Speed (rpm)	1791	1782	1773	1763	1752	1740	1756
Line Amperes	9.73	12.12	15.3	19	23.57	28.66	21.7

Motor Drawing



Appendix L: Electrical Specifications

Capacitor Calculations

Excitation Capacitor Calculations

$E := 460V$ $\qquad pf := .81$

$I_{full\_load} := 19 \cdot A$ $\qquad \omega := 2 \cdot \pi \cdot 60Hz$

Apparent Power

$S_{motor} := \sqrt{3} \cdot E \cdot I_{full\_load}$ $\qquad S_{motor} = 15.138\,kV \cdot A$

Real Power

$P_{motor} := S_{motor} \cdot pf$ $\qquad P_{motor} = 12.262\,kW$

Reactive Power

$Q_{motor} := \sqrt{S_{motor}^{\,2} - P_{motor}^{\,2}}$ $\qquad Q_{motor} = 8.877\,kV \cdot A$

$Q_{phase} := \frac{Q_{motor}}{3}$ $\qquad Q_{phase} = 2.959\,kV \cdot A$

$I_{capacitive} := \frac{Q_{phase}}{E}$ $\qquad I_{capacitive} = 6.433\,A$

$X_{capacitor} := \frac{E}{I_{capacitive}}$ $\qquad X_{capacitor} = 71.507\,\Omega$

Required Capacitance per phase

$C := \frac{1}{\omega \cdot X_{capacitor}}$ $\qquad C = 37.095\,\mu F$

AAC Table

Code Word	Size (AWG or kcmil)	Stranding		Diameter (ins.)		Cross-Sectional Area (Sq. ins.)	Weight Per 1000 ft. (lbs.)	Rated Strength (lbs.)	Resistance OHMS/1000 ft.		Allowable Ampacity+ (Amps)
		No. of Wires	Class	Individual Wires	Complete Cable				DC @ 20°C	AC @ 75°C	
Peachbell	6	7	A	0.0612	0.184	0.0206	25	563	0.658	0.805	103
Rose	4	7	A	0.0772	0.232	0.0328	39	881	0.414	0.506	138
Iris	2	7	AA, A	0.0974	0.292	0.0522	62	1350	0.260	0.318	185
Pansy	1	7	AA	0.1093	0.328	0.0657	78	1640	0.207	0.252	214
Poppy	1/0	7	AA, A	0.1228	0.368	0.0829	99	1990	0.164	0.200	247
Aster	2/0	7	AA, A	0.1379	0.414	0.1045	125	2510	0.130	0.159	286
Phlox	3/0	7	AA, A	0.1548	0.464	0.1317	157	3040	0.103	0.126	331
Oxlip	4/0	7	AA, A	0.1739	0.522	0.1663	198	3830	0.0817	0.0999	383
Sneezewort	250	7	AA	0.189	0.567	0.1964	234	4520	0.0691	0.0846	425

A typical table from a cable manufacturer will have a variety of useful values, including cable and strand diameter, weight per unit length, dc and ac resistance per unit length at a specified temperature, and maximum current carrying ability, among other values. The highlighted section is the 0 gauge wire; after considering voltage drop and cost, 0 gauge seems to be the best fit for this project application.

Voltage Drop Calculations

Cable Name	Gauge	Power (W)	Voltage (V)	Current (A)	AC Resistance (Ω/1000ft)	Length (km)	Length (10^3 ft)	Power Lost (W)	Voltage Drop (V)
Peachbell	6	11500	600	19.17	0.8050	12.0	39.370	185.15	9.660
Rose	4	11500	600	19.17	0.5060	12.0	39.370	116.38	6.072
Iris	2	11500	600	19.17	0.3180	12.0	39.370	73.14	3.816
Pansy	1	11500	600	19.17	0.2520	12.0	39.370	57.96	3.024
Poppy	0	11500	600	19.17	0.2000	12.0	39.370	46.00	2.400
Aster	00	11500	600	19.17	0.1590	12.0	39.370	36.57	1.908
Phlox	000	11500	600	19.17	0.1260	12.0	39.370	28.98	1.512
Oxlip	0000	11500	600	19.17	0.0999	12.0	39.370	22.98	1.199

Different gauges of wire have varying resistances per unit length. Resistance decreases as the cross sectional area of the wire increases. With significant lengths of wires, large resistances can pose a problem in the form of a voltage drop. The far right column of the above table shows the voltage drop of different gauges of wire after near 40,000 ft, which is the distance from the generator to the head of the village. The less the voltage droops there are, the better. Ideally, there would be no voltage drop, and the wall plug in a village home would read 120V out at 60 Hz.

Line Calculations

Sample Calculations for Single Phase Line Impedance and Admittance of a 1/0 Gauge 7-Strand All-Aluminum Conductor (AAC)

$f := 60 \cdot Hz$

$\omega := 2 \cdot \pi \cdot f$

$\varepsilon := 8.854 \cdot 10^{-12} \cdot \frac{F}{m}$

$Conversion := 34.8 \frac{m}{1000ft}$

$d_{bundle} := 0.368 \cdot in$

$d_{conductor} := 0.1228 \cdot in$

$d_{across} := 0.2456 \cdot in$

$d_{adjacent} := 0.22138 \cdot in$

$r_{prime} := 0.0478 \cdot in$

$D_{EQ} := 24 \cdot in$

$$GMR := \sqrt[49]{\left[\left(r_{prime} \cdot d_{conductor}{}^{6}\right) \cdot \left(r_{prime} \cdot d_{conductor}{}^{2} \cdot d_{adjacent}{}^{2} \cdot d_{across}{}^{2}\right)^{6}\right]}$$

$GMR = 0.147\,in$

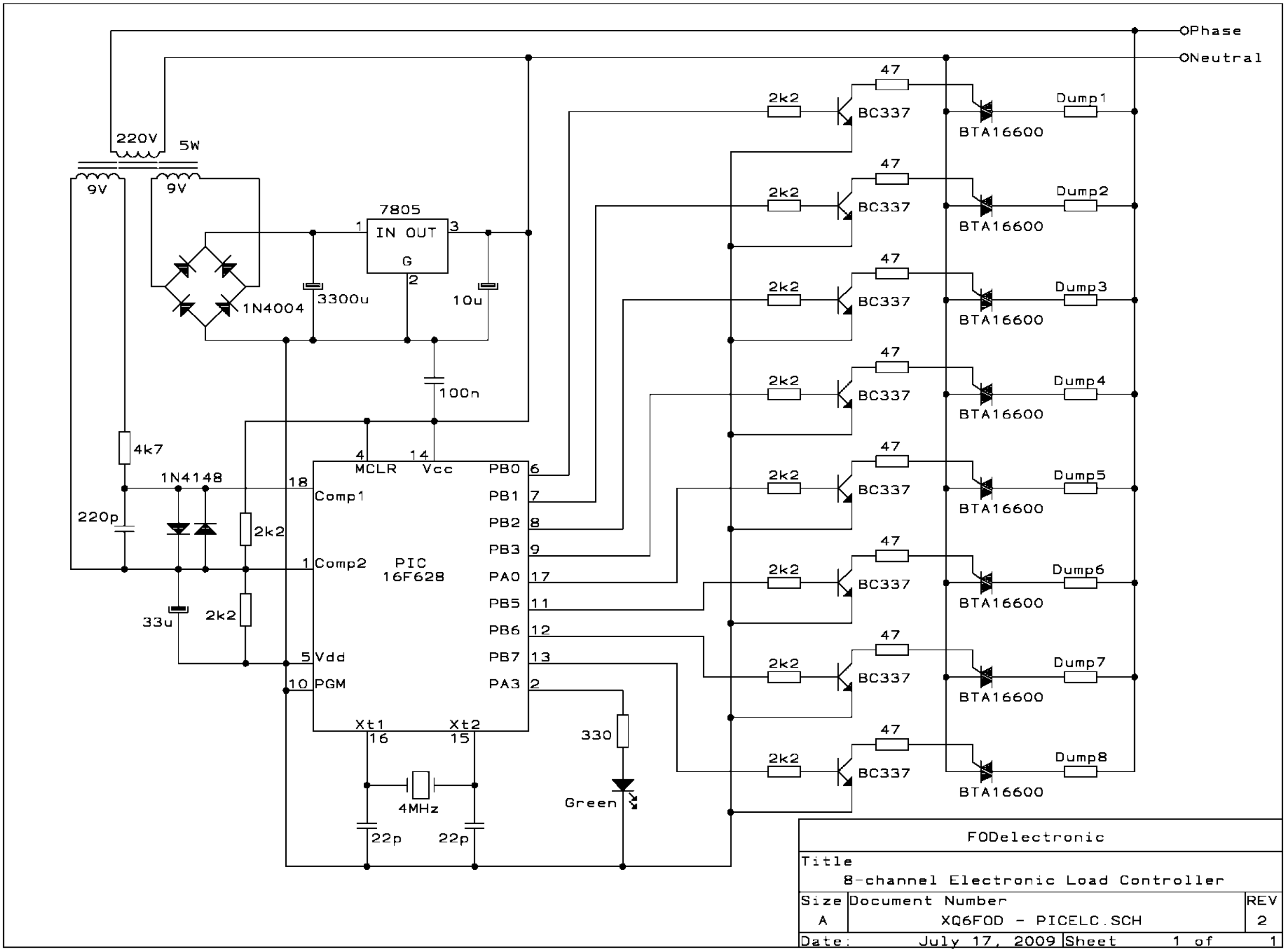
$R_{60Hz} := 0.2 \cdot \frac{\Omega}{1000ft}$

$$Z_{line} := R_{60Hz} + i \cdot 2 \cdot 10^{-7} \cdot \omega \cdot Conversion \cdot \ln\left(\frac{D_{EQ}}{r_{prime}}\right)$$

$$Y_{line} := \frac{(i \cdot \omega \cdot 2\pi \cdot \varepsilon \cdot Conversion)}{\ln\left(\frac{D_{EQ}}{\frac{d_{bundle}}{2}}\right)}$$

$Z_{line} := (.200 + i \cdot 0.0087229) \cdot \frac{\Omega}{1000ft}$ $\qquad$ $Y_{line} = 1.498i \times 10^{-7} \frac{S}{1000ft}$

Electronic Load Controller Schematic



Appendix M: Cost Estimate

Quantity	Unit	Item/Material	Base Cost	Extension Cost	Notes
Concrete					
		Materials:			
1.25	yard	Sand/Aggregate (aka *cascajo*)	$15	$19	
8	100lb sack	Cement	$10	$80	type 1 portland cement
		Tools:			
1	pc.	Level	$18	$18	
1	pc.	Concrete Hoe	$17	$17	
1	pc.	Float and/or darby	$18	$18	
64	foot	Rebar	$0.60	$38	
15	pc.	5-Gallon bucket	$3	$45	
1	pc.	Groover (for contraction joints)	$10	$10	
			Concrete Total	**$245**	
Penstock					
42	20 foot section	10" PVC pipe - 20'	$80	$3,360	
5	quart	PVC Primer	$10	$50	
4	gallon	PVC Adhesive (PVC Cement)	$45	$180	
			Penstock Total	**$3,590**	
Turbine					
1	3" x 10'	Stainless Steel Pipe	$196	$196	
2	pc.	Ball Valve	$10	$20	
1	25 foot section	PVC Tube - 150 psi	$120.75	$121	
			Turbine Total	**$337**	
Transmission					
420	pc.	Hardwood Poles			obtained locally
2	50-lb pail	Fencing Staples	$50	$100	harwareworld.com
6	340 foot bundle	Tie Wire	$4	$24	harwareworld.com
			Transmission Total	**$124**	
Technical Expertise					
80	hour	Electrical Contracting	$20	$1,600	
			Technical Services Total	**$1,600**	
		Estimate for Materials		**$5,900**	

Cost Estimate Continued

Initial Electrical Cost Analysis					
Quantity	**Item**	**Vendor**	**Base Cost**	**Extension Cost**	**Notes & Questions**
1	Baldor JMM2513T - 3 Phase Motor	Baldor	$1,806	$1,806	
1	Load Controller (IGC)	ATDER-BL, Nicaragua	$660	$660	
1	Ground Fault Interrupter (GFCI)	Grainger	$150	$150	
1	Capacitors - 3 @ 37.095µF	ATDER-BL, Nicaragua	$300	$300	
1	Transformer - 240V/600V 10kVA	transformeronline.com	$1,128	$1,128	
100	Transformer - 460V/120V 1kVA	transformeronline.com	$146	$14,600	
100	Electrical Boxes	Electrisa	$10	$1,000	
1000	4A Fuse	Digikey	$0.16	$162	F2511-ND (3AG size)
100	Panel Mount Fuse Holder - 3AG	Digikey	$2.34	$234	
1	2-pole, 60A Circuit Breaker - Main Disconnect	Electrisa	$120	$120	
13	km of #1/0 aluminum cable	Electrisa	$1,505	$19,565	
4	km of #2 aluminum cable	Electrisa	$1,312	$5,248	For in village distribution wiring.
25	500' roll of #12 cable	Electrisa	$53	$1,319	This is an initial estimate
	Estimate - Electrical Equipment Total			**$46,292**	
	Estimate - Materials			**$5,900**	
	Total Cost			**$52,200**	

As there are a few large industrial suppliers in Panama City, some costs were estimated using the following corporate website:

http://www.grainger.com/Grainger/wwg/start.shtml?cm_guid=1-_-100000000000001053399-_-4624274663&cm_mmc=PPC:%20Google-_-TPN%20-%20Brand-_-Grainger-_-grainger&gclid=CJGLiumn7KwCFUHRKgodI0izJg

This website is for Grainger. Grainger has a very comprehensive online catalog with items ranging from motors and electrical equipment to PVC piping and tubes.

Appendix O: Project Contacts

		Project Contacts for Piriatí, Panama site					
First Name	**Last Name**	**Relationship to Project**	**Affiliation**	**Professional Department**	**e-mail**	**phone number**	**miscellaneous**
Alexander	Baril	Electrical Engineering Student Consultant	Michigan Technological University	Electrical Engineering	arbaril@mtu.edu	1-586-306-0594	Graduating in Spring 2012
Tim	Burke	External Technical Project Guide	United States Peace Corps, Panama (former)		timothy.matthew.burke@gmail.com		Former PCV of Agua Fria Ipeti
Coy	Durham	In Country Project Guide	United States Peace Corps, Panama		thinkoutsideofthebox@yahoo.com		Current PCV of Agua Fria Ipeti
Katherine	Engels	Civil Engineering Student Consultant	Michigan Technological University	Civil Engineering	kfengels@mtu.edu	1-231-250-1614	Graduating in Fall 2011
Tyler	Fincher	Civil Engineering Student Consultant	Michigan Technological University	Civil Engineering	twfinche@mtu.edu	1-715-527-0470	Graduating in Fall 2011
Alan	Foster	In Country Project Guide	United States Peace Corps, Panama (former)		alan.t.foster@gmail.com		Former PCV of Piriati Embera
John	Lukowski	Electrical Engineering Faculty Mentor	Michigan Technological University	Electrical Engineering	jtlukows@mtu.edu	1-906-487-2545	
Alan	McDonald	In Country Project Guide & Translator	United States Peace Corps, Panama (former)		amcdnld@gmail.com	507-6709-2389	Former PCV of an Embera tribe
Rebecca	Prich	Electrical Engineering Student Consultant	Michigan Technological University	Electrical Engineering	rlprich@mtu.edu	1-989-280-8108	Graduating in Spring 2012
David	Watkins	Director International Senior Design	Michigan Technological University	Civil Engineering	dwatkins@mtu.edu	1-906-487-1640	
Joshua	Wiljanen	Mechanical Engineering Student Consultant	Michigan Technological University	Mechanical Engineering	jrwiljan@mtu.edu		Graduating in Spring 2012
Rodolfo							Official of Council in Piriati Embera
Kiser Hydro, LLC		Hydropower Specialization in the U.P. of MI	Corporate Contact	www.kiserhydro.com		1-231-250-1614	

Appendix P: Tim Burke's Feasibility Analysis

English Translation

Feasibility Study

Micro-hydro system - Piriatí Emberá

June 17, 2010

Introduction

The leaders of the Emberá Piriatí community, located in the village of Tortí, commissioned a study of the feasibility of a micro-hydro to generate electricity for the people. This would replace the existing system that uses a diesel generator to be described in the next section. The community consists of 120 houses.

Existing System

13 years ago, a project of the Rural Electrification Office (ERO), the community achieved a basic electrification system. The system consists of a three-phase diesel generator with a power that the author estimated at 15 kVA., Since it did not have any indication and voltage indicator itself was damaged. The calculation is based on the memories of community leaders who claimed that the power indicator up to 50 amps and voltage indicator used to go up about 120 volts. Since the system is three phase, this indicates a load of 5 kVA. per phase and 15 kVA. in total.

The generator is connected to the homes of the community through a distribution network with high normal bare aluminum conductors. The three phases up to high voltage and divide the three parts of the community. The power line is lowered to 120 volt transformers to connect the houses. No load balancing system continued in three phases.

In actuality, the community often starts the generator due to high fuel prices. The leaders commented to the author who used the generating only about 3 hours a week. However, the existence of a distribution network would significantly reduce the cost involved in any micro-hydro system, since it would not have its own network.

The water source

The only source of water nearby is the river Piriatí which has its headwaters in the mountains above the community. At the time of the study, which was in winter, the river flow was above 1000 liters per second. However, almost devoid of localized decline. The only notable break gave the river was at 2.6 km from the center of the community in a straight line and had a height of less than 2 meters. So any system must be by a long channel that uses the river's natural inclination. Thick with GPS measurement indicates there is a gap between the break and the community of about 30 meters, with a slope of 1%. Figure 1 indicates the proper design.

Depending on the type of soil present, the channel should be sealed with concrete and excavated soil could be compacted with local labor, significantly reducing system cost.

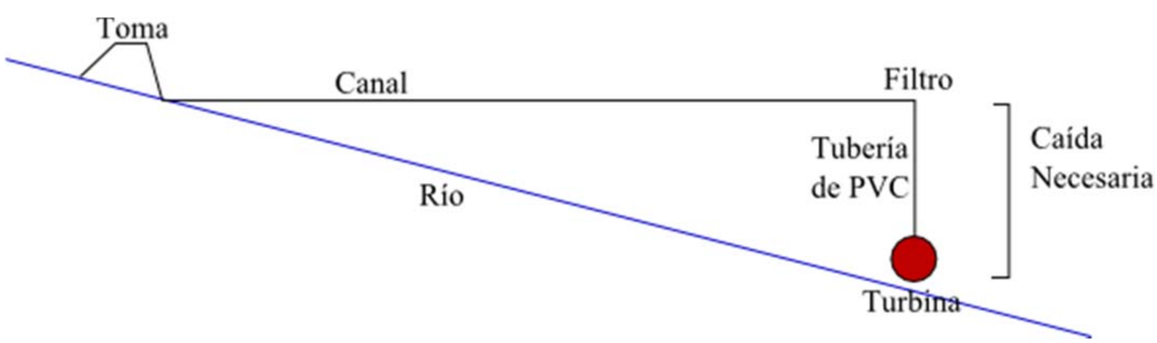


Figure 1: Diagram of system

In actuality, seasonal variations are unknown river, which implies an uncertainty in the recommendations that can this study. So power threads then presented a range of options depending on the flow remains in the river throughout the year.

Power Site

The power of place depends on two factors: the available bandwidth and the gap between the inlet and turbine system shown in Figure 1. A micro-hydro system can not get the total flow of a river because he always has to keep a quantity of water at its source to fulfill its ecological role. So the system design flow can not add more than 50% of total river flow. Table 1 shows the possible flow to the percentage of summer drought experienced by the River.

Reduction of total flow volume (gpm) flow usable (lps)

Reducción de caudal	Caudal total (lps)	Caudal usable (lps)
50%	634	317
60%	507	254
70%	380	190
80%	254	127
90%	127	63

Table 1: Flow available in summer

The gap this depends on the length of the canal built. Table 2 presents the various options. Note that the powers given are that the overall system performance is 50% and has a 20% loss of energy due to friction in the pipe between the channel and the turbine.

The figures indicate that a channel of 750 meters, the system can outperform the existing generator in the winter. The summer power shown in Table 3. It is noted that these data are based on a measurement of height with GPS, which is always imprecise, so actual figures may vary up to 30% of those given.

Channel length (m) Available Fall (m) Winter Power (kW)

Longitud del canal (m)	Caída disponible (m)	Potencia en invierno (Kw.)
500	5	12
750	7.5	19
1000	10	25
1250	12.5	31
1500	15	37

Table 3 is understood in the following way. The row indicates the length of the channel and the column the percentage of drought, or the percentage by which the river is reduced in summer. For example, a percentage of drought indicates that only 90% remaining 10% of the winter flow during summer. The corresponding figure for a length and a percentage is the power of the system (in kW.) In summer under these conditions.

Channel length (m)

	Longitud de canal (m)					
Reducción de caudal		50%	60%	70%	80%	90%
	500	6.2	5.0	3.7	2.5	1.2
	750	9.3	7.5	5.6	3.7	1.9
	1000	12.4	9.9	7.5	5.0	2.5
	1250	*15.5*	12.4	9.3	6.2	3.1
	1500	*18.6*	*14.9*	11.2	7.5	3.7
	1750	*21.7*	*17.4*	13.0	8.7	4.3

Table 3: Power in summer

As shown in Table 3, only in some cases (the green-red) would be available 15 Kw. power in the summer. These cases correspond to a channel of more than 1.5 km and a maximum dry cup of 60%. A flow study will be conducted in the summer to say with certainty that the power actually available.

Transmission System

The turbine and generator of the system will have to connect to the existing distribution network via an elevated line of high voltage transmission. Depending on the length of the channel this line can be between 1 and 1.5 km in length. Since the voltage is unknown current distribution and characteristics of loads, this study should be as follows.

• The high voltage current network is 415 volts

• The voltage drop of the current network does not add up to over 5%

• The system will have a power of 15 Kw.

• The power factor (cos φ) is 0.8

• The three phases are balanced

These five assumptions allow estimation of the cost of connecting a proposed hydroelectric system to the existing distribution network in the community. Table 4 summarizes the results.

Potencia total (Kw.)	15	Voltaje de trasmisión (V)	415	
Potencia aparente (kVA.)	18.75	Distancia (Km.)	1.5	1
Corriente por fase (A.)	15	Caída de voltaje (%)	7.3	4.8
Tipo de cable indicado (fase)	#4 aluminio forrado	Pérdida de energía (%)	3	2
Tipo de cable indicado (neutral)	#7 aluminio forrado	Costo total (miles de dol.)	7	4.7

(Table translation:

Total power (kW) 15 transmission voltage (V) 415

Apparent power (kVAR) 18.75 Distance (km) 1.5 1

Current per phase (A) 15 Voltage Drop (%) 7.3 8.4

Cable type indicated (phase) # 4 aluminum siding energy loss (%) 3 2

Cable type indicated (neutral) # 7 aluminum siding Total cost (thousands of dol.) 7 4.7)

Table 4: transmission system

The costs given above does not include the price of transformers because they assume that the generator is set to generate at 415 volts (high voltage distribution network). As shown in the table, a transmission line of 1.5 km would cost around B /. 7,000.00 in cable only, while a line of 1 km would cost B /. 4,700.00. This cost does not include the cost of poles and insulators because it is assumed that the posts are of local contribution and that the cables do not require special insulation lining.

Next Steps

To refine the estimates given above and ensure proper system design, the author recommends that the community of Piriatí perform the following activities.

• Analyze and determine the amount of funds available for the project and start of acquisition management.

• Build a dam measuring the river during the summer to precisely measure the flow of the river at that time. The author can provide instructions on building it.

• Find out the possibility of the arrival of the national network of community electrification in the short to medium term, which hydroelectric system unusable.

Contact details

The author and manager of this study was Mr. Timothy Burke, Peace Corps volunteer in the community of Cold Water Ipetí, Tortí village of the district of Chepo. For matters related to this study or to request a review by another site, you can contact him at 6017-3080 or e timburke@alumni.rice.edu.

Español Versión

Estudio de Factibilidad

Sistema Microhidroeléctrico – Piriatí Emberá

17 de junio de 2010

Introducción

Los dirigentes de la comunidad de Piriatí Emberá, ubicada en el corregimiento de Tortí, comisionaron un estudio de la factibilidad de un sistema microhidroeléctrico para generar electricidad para el pueblo. Dicho sistema reemplazaría el existente que emplea una generadora de diesel que se describirá en la sección siguiente. La comunidad consiste en 120 casas.

Sistema Existente

Hace 13 años, mediante un proyecto de la Oficina de Electrificación Rural (OER), la comunidad logró un sistema de electrificación básico. El sistema consta de una generadora trifásica de diesel con una potencia que el autor calcula en 15 Kva., ya que la misma no contaba con ninguna indicación y su propio indicador de voltaje era dañado. El cálculo se basa en los recuerdos de los dirigentes de la comunidad que afirmaron que el indicador de corriente subía hasta 50 amperios y el indicador de voltaje solía subir alrededor de 120 volteos. Puesto que el sistema es trifásico, eso indica una carga de 5 Kva. por fase o 15 Kva. en total.

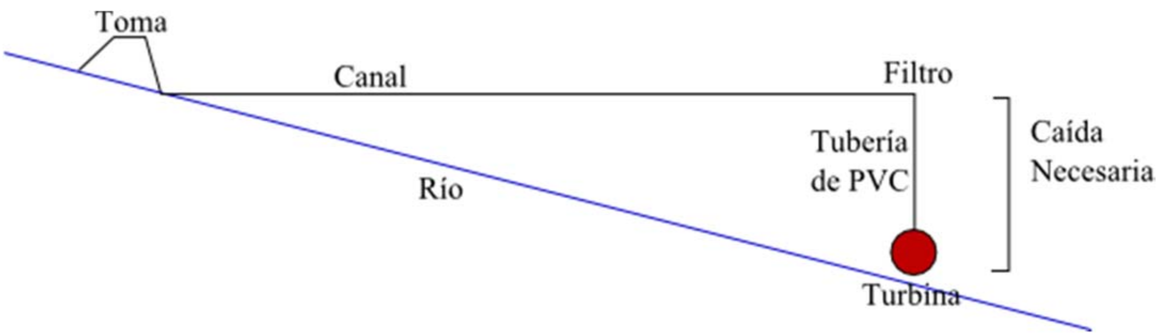
La generadora se conecta a las casa de la comunidad mediante una red elevada normal de distribución con conductores desnudos de aluminio. Las tres fases se suben a alta tensión y se dividen a las tres partes de la comunidad. La línea de alta tensión se baja con transformadores a 120 volteos para que las casas se conecten. No hay sistema de balance de carga continuo en las tres fases.

En actualidad, la comunidad no arranca la generadora con frecuencia debido al alto precio de combustible. Los dirigentes comentaron al autor que usaban la generadora solamente unas 3 horas a la semana. Sin embargo, la existencia de una red de distribución reduciría significativamente el gasto implicado en cualquier sistema microhidroeléctrico, ya que el mismo no tendría que contar con su propia red.

La fuente de agua

La única fuente de agua cercana es el río Piriatí que tiene su cabecera en las montañas arriba de la comunidad. Al tiempo del estudio, que era en pleno invierno, el río tenía un caudal por encima de 1000 litros por segundo. Sin embargo, casi carecía de caída localizada. El único salto notable que dio el río era a 2.6 kilómetros del centro de la comunidad en línea recta y tenía una altura de menos de 2 metros. De modo que cualquier sistema tendrá que ser mediante un canal largo que aprovecha la inclinación natural del río. Una medición gruesa con GPS indica que hay un desnivel entre el salto y la comunidad de alrededor de 30 metros, siendo una inclinación de 1%. Figura 1 indica el diseño apropiado.

Dependiendo del tipo de suelo presente, el canal no tendría que ser sellado con concreto y podría ser excavado en tierra compactada con labor local, reduciendo significativamente el costo del sistema.



En actualidad, se desconocen las variaciones estaciónales del río, lo cual implica un incertidumbre en las recomendaciones que puede dar este estudio. De modo que las discusiones de potencia a continuación presentarán una gama de opciones según el caudal que permanece en el río todo el año.

Potencia del sitio

La potencia del lugar depende de dos factores: el caudal disponible y el desnivel entre la toma y turbina del sistema, indicado en Figura 1. Un sistema microhidroeléctrico no puede aprovechar el caudal total de un rió porque siempre tiene que mantenerse una cantidad de agua en su fuente para que desempeñe su papel ecológico. Así que el caudal de diseño del sistema no puede sumar a más de 50% del caudal total del río. Cuadro 1 presenta los caudales posibles de verano según el porcentaje de sequía que experimenta el río.

Reducción de caudal	Caudal total (lps)	Caudal usable (lps)
50%	634	317
60%	507	254
70%	380	190
80%	254	127
90%	127	63

El desnivel presente depende de la longitud del canal construido. Cuadro 2 presenta las varias opciones. Nota que las potencias dadas suponen que el rendimiento total del sistema sea 50% y que haya una pérdida de 20% de energía debido a fricción en la tubería entre el canal y la turbina.

Las cifras indican que con un canal de 750 metros, el sistema puede superar a la generadora existente en invierno. La potencia en verano se indica en Cuadro 3. Se nota que estos datos se basan en una medición de altura con GPS, lo cual siempre es impreciso, de modo que las cifras actuales pueden variar hasta 30% de éstas dadas.

Longitud del canal (m)	Caída disponible (m)	Potencia en invierno (Kw.)
500	5	12
750	7.5	19
1000	10	25
1250	12.5	31
1500	15	37

Cuadro 3 se entiende en la siguiente manera. La fila indica la longitud del canal y la columna el porcentaje de sequía, o sea el porcentaje en que el río se reduce en verano. Por ejemplo, un porcentaje de sequía de 90% indica que solamente permanece 10% del caudal de invierno durante verano. La cifra correspondiente a una longitud y un porcentaje es la potencia del sistema (en Kw.) en verano bajo esas condiciones.

Longitud de canal (m)					
Reducción de caudal	**50%**	**60%**	**70%**	**80%**	**90%**
500	6.2	5.0	3.7	2.5	1.2
750	9.3	7.5	5.6	3.7	1.9
1000	12.4	9.9	7.5	5.0	2.5
1250	*15.5*	12.4	9.3	6.2	3.1
1500	*18.6*	*14.9*	11.2	7.5	3.7
1750	*21.7*	*17.4*	13.0	8.7	4.3

Como se ve en Cuadro 3, solamente en algunos casos (los colorados de verde) se dispondría 15 Kw. de potencia en verano. Esos casos corresponden a un canal de más de 1.5 Km. y una taza de sequía máxima de 60%. Un estudio de caudal tendrá que realizarse en verano para poder decir con certidumbre la potencia que realmente se disponga.

Sistema de transmisión

La turbina y generadora del sistema tendrán con conectarse a la red existente de distribución mediante una línea elevada de transmisión a alta tensión. Dependiendo de la longitud del canal esta línea puede ser de entre 1 y 1.5 Km. de longitud. Siendo que se desconoce el voltaje actual de la red de distribución y las características de las cargas, este estudio supondrá lo siguiente.

- La tensión alta de la red actual es 415 volteos
- La caída de voltaje de la red actual no suma a más de 5%
- El sistema tendrá una potencia de 15 Kw.
- El factor de poder (cos ϕ) es 0.8
- Los tres fases están balanceados

Estas cinco suposiciones permiten la estimación del costo de conectar un propuesto sistema hidroeléctrico a la red de distribución existente en la comunidad. Cuadro 4 resume los resultados.

Potencia total (Kw.)	15	Voltaje de trasmisión (V)	415	
Potencia aparente (kVA.)	18.75	Distancia (Km.)	1.5	1
Corriente por fase (A.)	15	Caída de voltaje (%)	7.3	4.8
Tipo de cable indicado (fase)	#4 aluminio forrado	Pérdida de energía (%)	3	2
Tipo de cable indicado (neutral)	#7 aluminio forrado	Costo total (miles de dol.)	7	4.7

Los costos dados arriba no incluyen el precio de transformadores porque suponen que la generadora sea ajustada para generar a 415 volteos (la tensión alta de la red de distribución). Como se ve en el cuadro, una línea de trasmisión de 1.5 Km. costaría alrededor de B/. 7,000.00 en cable solamente, mientras que una línea de 1 Km. costaría B/. 4,700.00. Esto costos no incluyen el gasto de postes ni aisladores porque se supone que los postes sean de aporte local y que los cables forrados no requieren aislamiento especial.

Pasos siguientes

Para refinar los estimados dados arriba y asegurar el buen diseño del sistema, el autor recomienda que la comunidad de Piriatí realice las actividades siguientes.

- Analizar y decidir la cantidad de fondos que se disponga para el proyecto y empezar la gestión de su adquisición.
- Construir una represa de medición en el río durante el verano para medir precisamente el caudal del río en esa época. El autor puede proveer instrucciones acerca de la construcción de la misma.
- Averiguar la posibilidad de la llegada de la red nacional de electrificación a la comunidad a corto o mediano plazo, lo cual inutilizaría un sistema hidroeléctrico.

Datos de contacto

El autor y encargado de este estudio es el Lic. Timothy Burke, voluntario del Cuerpo de Paz en la comunidad de Agua Fría de Ipetí, corregimiento de Tortí, distrito de Chepo. Para asuntos relacionados a este estudio o para solicitar el estudio de otro sitio, se puede contactarlo al 6017-3080 o al correo timburke@alumni.rice.edu.