Zapatero Engineering

Micro-Hydroelectric Power for Majé Chimán

Tyler Losinski, Christine Matlock, Katherine Price, Andrea Walvatne

International Senior Design

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MichiganTech

Civil and Environmental Engineering Department

Disclaimer

The following report represents the work done by undergraduate students studying in the Department of Civil and Environmental Engineering and the Department of Mechanical Engineering of Michigan Technological University. The engineering work displayed here should not be considered professional engineering and would require professional review if implementation was considered.

Acknowledgements

Department of Civil and Environmental Engineering

David Watkins, PhD

Michael Drewyor, P.E., P.S.

J.Cole, Student

Kelli Whelan, Graduate Student

Department of Electrical and Computer Engineering

John Lukowski

Alan Foster, Previous Peace Core Worker

Larry Belkin, CH2M Hill

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Mission Statement

Zapatero Engineering has defined their mission statement for the senior design project as part of International Senior Design as:

> *"Through avenues of learning, communication, and innovation our cross functional engineering team strives to improve lives through design of sustainable energy systems."*

Zapatero Engineering also took the Wounan word for learning, "Mua kao gap um" as the Team's motto. It reminds the Team that one should always continue to learn in all engineering endeavors.

Executive Summary

Zapatero Engineering has completed a design of a micro-hydroelectric power system for the Wounan community of Majé Chimán in eastern Panama. Alan Foster, a previous Peace Corps volunteer, had completed initial surveys to identify this community as having the potential for such a system.

As part of the International Senior Design field experience, five senior design students forming Zapatero Engineering traveled to Panama in August 2012. The team stayed in the community for seven days during which necessary data and information was collected. The community has an existing and working electrical system using a diesel generator; an extensive side walk system and a water distribution system.

Zapatero Engineering utilized their diverse backgrounds of environmental, civil and mechanical engineering during the Fall 2012 semester to design a micro-hydroelectric power system to replace the existing diesel generator and produce consistent electricity for the community. The system design, as well as cost estimates, construction schedule, and construction and maintenance guides, were all aspects of the final product.

Before the design process was started, Zapatero Engineering constructed a list of design objectives and constraints. Objectives included aspects such as providing a safe electrical system that would provide 100 kW of power to the community and have a capital cost under $150,000. Minimizing the environmental impacts and allowing for easy installation were also identified as design objectives. Design constraints outlined the criteria the Team had to design within, such as available head, river flow rate, distance from the community and seasonal changes.

Taking these objectives and constraints into consideration, the Team was able to complete a full system design. The system will use approximately half the river flow from the Zapatero River at Chorro waterfall, utilizing the 27.5 meter (90 feet) of head, to produce 78 kW of consistent power for the community. The water will first be diverted to a forebay, or holding tank, by a diversion channel to insure consistent flow. From the forebay, the water will be directed by an 18 inch diameter, schedule 40, PVC pipe across 670 feet to a cross flow turbine connected to a synchronous generator. Electricity will be conducted at high voltage through a buried cable from the generation site to the community and tied into the existing infrastructure.

The total system cost, including construction materials, skilled labor and equipment, is estimated to be just under $477,000. The most costly aspects of the design include the turbine, transmission lines and generator house electronics. The construction schedule indicates two years of construction activities, including construction of a major path to the generation site.

In order to insure this project was suitable for the community, the Team investigated environmental and social impacts, sources of funding and energy source alternatives. While the final design did fall short of some of the design objectives originally envisioned, the culmination of work included in the report represents each aspect of the design and the resulting full system solution for the electrical needs of the Wounan people of Majé Chimán.

1.0 Introduction

International Senior Design is an alternative to the standard senior design at Michigan Tech. This program, also known as iDesign, provides students the opportunity to complete a design project purposed for a developing community. The international field experience portion of the program brings the students to the community prior to the design semester for assessment and data collection. The goal of iDesign is to “provide a unique capstone senior deign experience that involves service learning in an international, multicultural context” [1].

1.1 Project Overview

Zapatero Engineering is an iDesign team comprised of undergraduates Tyler Losinski, studying Mechanical Engineering; Christine Matlock, studying Civil Engineering; Katherine Price, studying Environmental Engineering and Andrea Walvatne, studying Mechanical Engineering.

The Team traveled to the community Majé Chimán in eastern Panama in August 2012. For seven days the team resided in the community. During this time, Zapatero Engineering identified the need for a consistent and sustainable power source. The current main source of electricity came from a centralized diesel generator. The shortcoming of this system was the increasing operational cost of the generator due to the rising fuel prices and increasing cost of transportation. This has forced the community to only operate the generator during occasional evenings when diesel fuel is available. The current generator outputs up to 110 kW, which has proven to be sufficient for the community’s current evening electrical needs. Additional sources of energy are provided by propane and a few personal solar panels.

Fortunately, due to the mountainous terrain and the nearby river systems, Majé is established in a location with the potential for a micro-hydroelectric system. Zapatero Engineering collected data for the proposed hydroelectric system through surveying, photography, Global Positioning System (GPS) waypoints and community surveys.

The Team returned to the United States and spent the following fall semester designing a micro-hydroelectric system from the data collected in country. The Team generated a proposed design, cost estimates, construction schedule and guide as well as impact assessments.

1.2 Community and Area Background

Approximately one thousand people reside in 114 houses throughout the Majé Chimán community, which is located in a mountainous region of eastern Panama, as seen in Figure 1. This community is accessible by a two-track road, exclusively during the dry season, or by a sixty-five mile boat ride from the port of Coquira. Beautiful wood carvings and intricate basket weavings, culturally specific to the Wounan people, are the main source of income to the village. Small scale agriculture, as well as fishing, also adds to the community's economy.

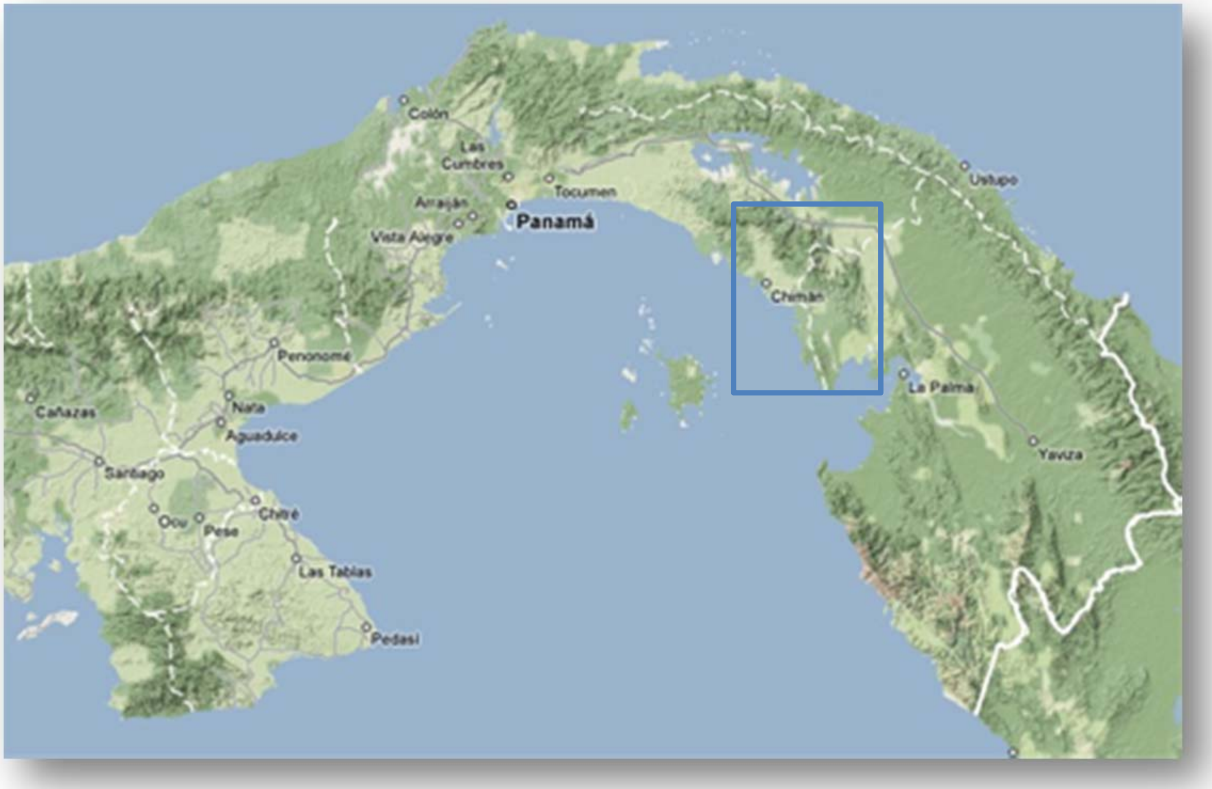


Figure 1: Republic of Panama Map and Location of Majé Chimán, Picture by Google Maps

The community places high priority on the education of their children. Although traditional Wounan is spoken as the primary language in the homes, Spanish is taught in the schools to meet the demands of globalization. A traditional child will experience formalized education through the ninth grade and could potentially continue with secondary school outside the village. The school facility, a point of pride for the community, is well maintained by the efforts of all community members.

An additional emphasis within the tribe is preserving their cultural heritage. Through traditional dances, language, crafts, body art and dress; the community has a rich culture that continues to thrive. As their current economic avenues are becoming insufficient, the tribe has expressed interest in bringing ecotourism into their community to share their traditional way of life.

The community is well organized, and members have a great sense of responsibility to each other. The tribe is organized by a hierarchy system, with a chief elected every five years. Committees exist to help advise the chief and lead the community. An example is the established water committee, which is in charge of the water system in the village. The electrical committee is made up of five members who help to maintain the current electrical system. Fifteen years ago, the government installed the infrastructure to power the basic electrical needs for Majé by the means of a diesel generator. Other governmental projects include a system of sidewalks throughout the community and a gravity-fed water distribution system. Due to the current political nature of the government, the social welfare programs have subsided and the Republic of Panama has progressed to a more capitalistic nation, placing rural communities at somewhat of a disadvantage.

2.0 Methods and Objectives

An extensive assessment of the village and surrounding area was completed while the Team resided in the community. From this assessment, the Team was able to define the objectives and constraints after returning to the U.S., which provided a framework for the rest of the project.

2.1 Site Assessment

Zapatero Engineering traveled to the community with three main assessment goals: to assess the needs of the community, assess the existing resources, and assess the potential energy generation sites.

Community Mapping

A significant electrical infrastructure was previously established in Majé by the Panamanian Government. A GPS was employed to record portions of the community's extensive transmission lines. Resources commonly used within the community were also noted to determine the most probable materials to be used during the potential construction of a micro-hydroelectric system. A map of these GPS points and other maps of the community can be found Appendix A – Community and Waterfall Mapping.

Community Surveys

To guide Zapatero Engineering's design process, an electrical aspiration assessment was completed to ensure that the system to be designed would meet the community's current and future needs. A statistically significant, twenty-two interviews were performed at various locations in the community, a map of which can be found in Appendix A. A standardized set of interview questions were used with each interviewee to ensure consistency. The trends that emerged from the interview process were commonalities in the kinds of electrical appliances that the community desired as well as why they wanted these items. These interviews provided Zapatero Engineering with not only valuable quantitative data but also significant cultural insights. The results of this assessment can be found in Appendix B - Community Survey Results.

River Assessment

Zapatero Engineering needed to determine the electrical energy potential of the micro-hydroelectric site. The Team observed two potential locations- Salto Falls, a small waterfall five and a half miles (9 km) from the community and Chorro Falls, a larger waterfall seven miles (11 km) away as seen in Figure 2. At both sites, the flow rate and the cross-sectional area were recorded. A combination of an Abney level, GPS, stop watch, bottle and a string were employed to survey the terrain of the waterfalls. Extensive pictures and hand drawn maps were completed to document the waterfall and surrounding area for future reference.

Figure 2: Chorro Water Fall
Picture by J.Cole

2.2 Design Objectives

A list of objectives for the micro-hydroelectric design is shown in Table 1. Given known funding sources, such as the United Nations Development Program, it would be ideal to keep the total system cost under $150,000. This budget will be divided up as necessary between the cost of materials, cost of any required manufacturing, purchased components, and installation. Another objective that Zapatero Engineering is striving to achieve is the ease of installation. The Team also understands the struggles with system maintenance that may arise within the community, so another objective is to keep regularly scheduled upkeep to 10% of the total system cost per year. This will be accomplished by designing the micro-hydroelectric system to be as simple as possible. The Wounan people are very environmentally conscious, which leads

Zapatero Engineering to indicate minimizing the environmental impacts as its next objective. This will be addressed by not allowing more than a 10% increase in turbidity of the river water compared with the river's pre-existing conditions. This can be monitored by the village with turbidity meters once construction has begun. Completing a design that will provide 100 kW of power to the community is the Team's last objective.

The priority ratings, high medium and low, were chosen based on the community's needs and the probability of system implementation. System cost and power generation are ranked highest due to the idea that if both of these targets were not achieved, the prospect for the installation of a micro-hydroelectric system for the community of Majé Chimán is minimal. Following those, maintenance was given the next highest priority rating, as the Team wants to ensure that the system can be sustainable for the community to operate. Ease of installation and environmental impacts are the final objectives and obtain a priority ranking of low. Although still very important to consider, Zapatero Engineering feels that meeting these objectives do not fully determine the feasibility of a micro-hydroelectric implementation.

Table 1: Design Objectives

Objective Name	Priority	Method of Measurement	Objective Direction	Target
System Cost	High	Total System Cost	Minimize	$150,000
Ease of Installation	Low	Cost of Professional Labor	Minimize	$15,000
Maintenance	Medium	Cost and Time	Minimize	10% of System Cost
Environmental Impacts	Low	Turbidity Measurements Down	Minimize	10% Increase of
Power Generation	High	Available Watts in Community	Maximize	100 KW

2.3 Design Constraints

A list of five design constraints for the micro-hydroelectric system is displayed in Table 2. A key design constraint for the team is safety. Due to the high voltage potential of the system, there are many electrical hazards. If any community member is going to be at risk of a serious injury or death, the implementation of the design should not move forward. The amount of head that is available for power generation is constrained at 98 feet (30 meters). In addition, the amount of water in the Zapatero River during the dry season is estimated to be 35 ft^3/s (1 m^3/s). While the team was in the community during the wet season, this dry season flow was estimated conservatively from flowrate measurements and the community members' knowledge about the dry and wet season flows of the Zapatero River. This is a conservative number to ensure that adequate water can be supplied to the turbine at any given time throughout the year. The distance of Chorro Falls from the community is another constraint that must be considered. Finally, there are unique transportation limitations due to the wet season. This constraint restricts the duration of the transportation window to only three months out of the year.

Table 2: Design Constraints

Constraint	Method of Measurement	Limit
Safety	Number of Injuries/Deaths	0
Available Head	Surveying and Head Loss Calculations	30 Meters
Water	Measure the Zapatero River Flow Rate	1 Cubic Meter per Second
Location	Distance From Community	11 Kilometers
Transportation Timeframe	Time in which materials can be transported to site	3 Months/year

3.0 Micro-Hydroelectric Design Aspects

A micro-hydroelectric system conveys water from a high elevation to a lower elevation through a penstock to a turbine. The turbine then converts the kinetic and pressure energy of the water to mechanical energy which is then converted to electric energy by a generator. This electricity is then transported through transmission lines. A depiction of a general micro-hydroelectric system can be seen in Figure 3. The following sections outline each aspect of the micro-hydroelectric system Zapatero Engineering designed for the community in Majé Chimán.

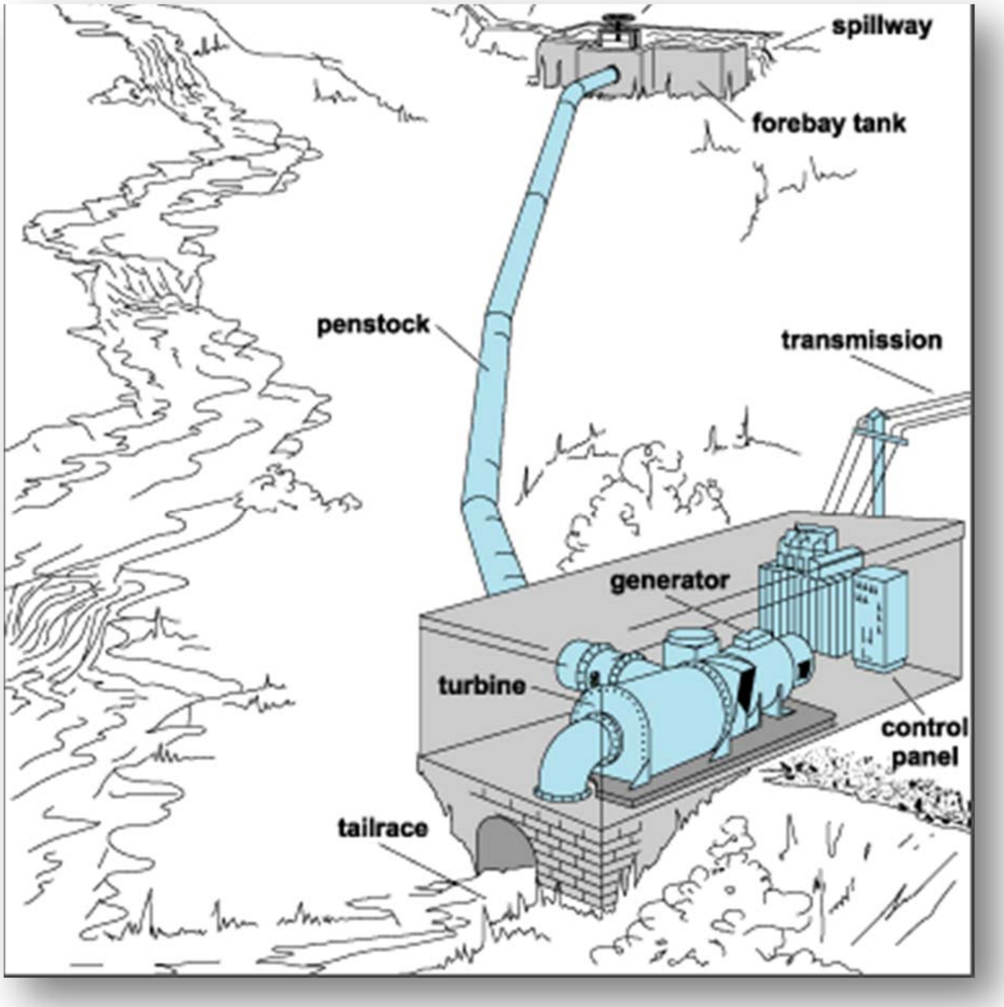


Figure 3: Example of a micro-hydroelectric system [2]

3.1 Diversion Structure

The proposed system utilizes up to half of the river flow, approximately 17.5 cfs. In order to capture this flow a diversion structure, similar to the one pictured in Figure 4, will be constructed using rocks and metal mesh. The diversion structure will continue to a channel which will be carved through the rock bank of the river or dug into the clay and lined with rocks. The dimensions of this channel can be found in Appendix B-Diversion and Forebay.

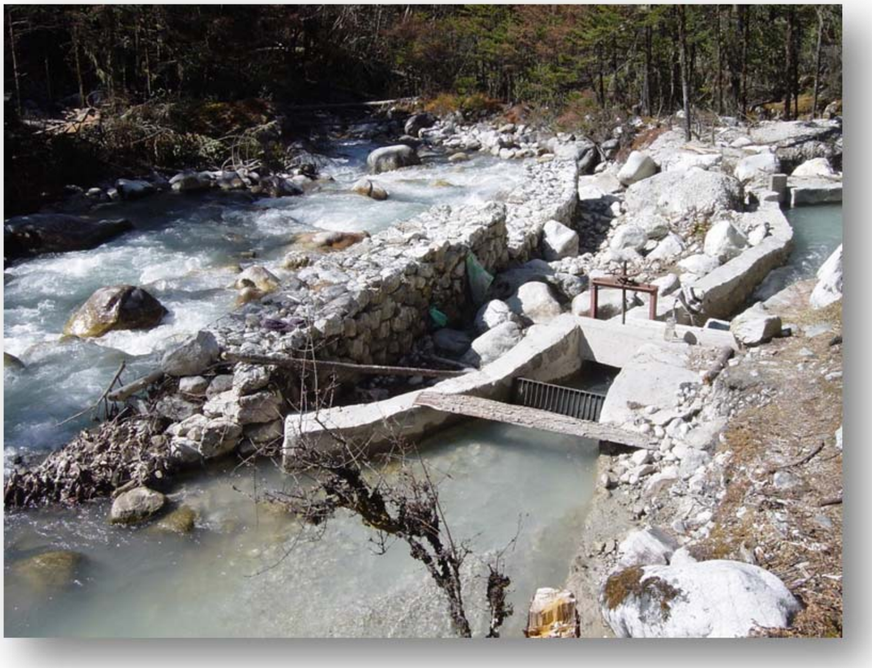


Figure 4: Example of rock diversion channel for conveying a portion of river flow
Picture by Nirmal Joshi, [3]

3.2 Forebay

A forebay structure acts as a holding station for the diverted water before it traverses through the penstock. This allows the flow reaching the turbine to be consistent. Without a forebay the flow in the penstock would be subject to the changing river level, and the inconsistent flow could result in inadequate power generation and additional strain on the generator. Many forebay structures have a large settling chamber as well as a holding chamber. The Zapatero River is rock-lined and has low sediment concentrations, so for ease of construction and cost savings the settling chamber was removed from the design. A bar screen with half inch openings will be placed in the channel before the entrance to the forebay to prevent large debris from entering the structure. Figure 5 is a SolidWorks® model of the forebay design. The forebay is 12 feet by 12 feet by 12 feet and allows for 1,331 cubic feet of water storage. The structure will be constructed from concrete and will have a plastic corrugated cover to keep out falling debris. The forebay has an overflow structure that allows for a constant level of water. The overflow structure will return water back to the river. Full design calculations can be found in Appendix C-Diversion and Forebay.

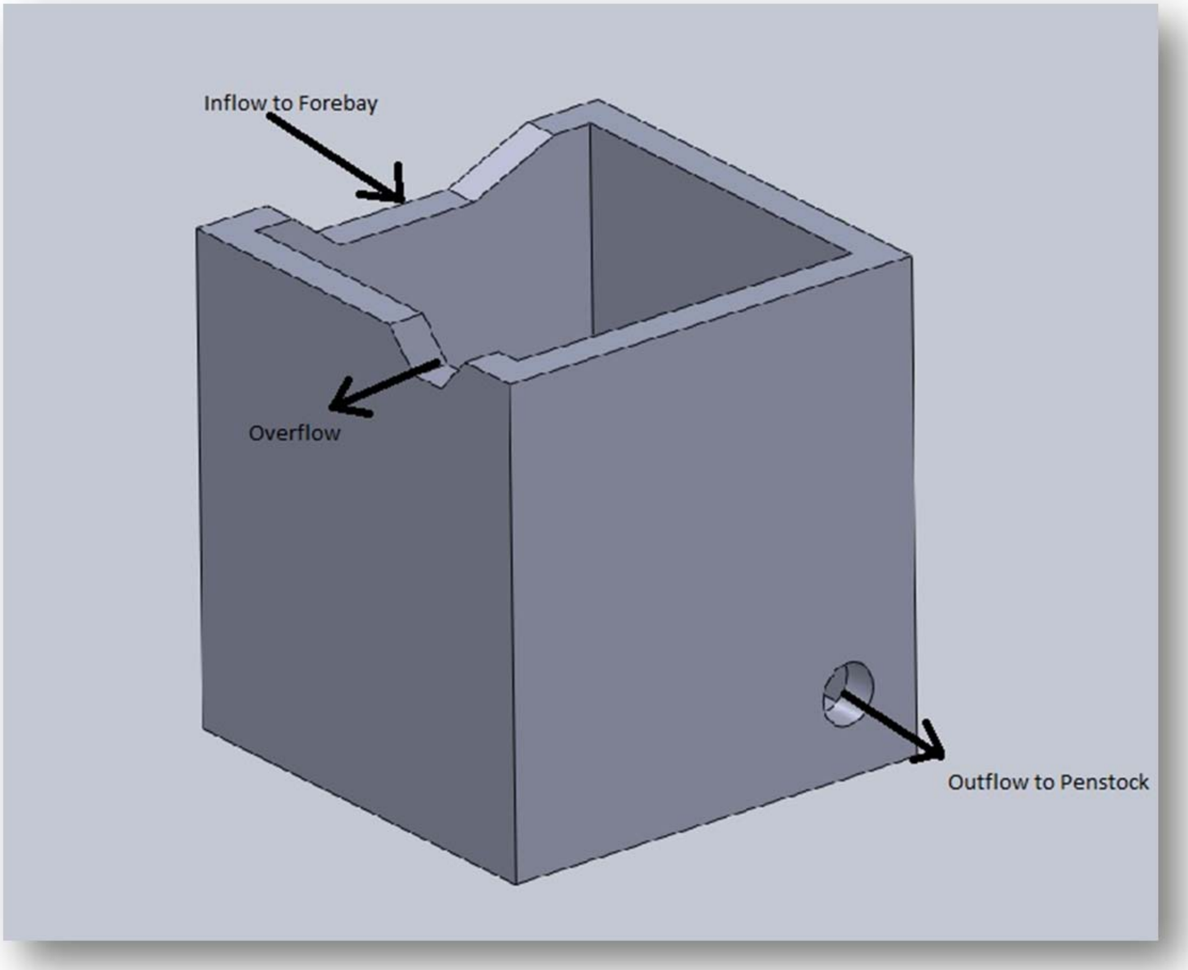


Figure 5: Solid Works Model of Forebay
Model by Christine Matlock

3.3 Penstock

The penstock structure diverts the water from the forebay and transports the flow to the turbine. Zapatero Engineering performed a hydraulic analysis on the penstock system to determine the optimal pipe size and material. The analysis showed that PVC pipe would contribute the least amount of headloss due to friction. Although an 18 inch, schedule 40 PVC pipe experiences 16 feet (4.8 meters) more headloss compared to a 24-inch diameter pipe, the 18-inch diameter was chosen for the $16,000 cost savings associated with it. The process of headloss determination and pipe selection can be found in greater detail in Appendix D-Penstock. The path of the penstock is not fully known because the team was unable to survey the area around the waterfall due to time constraints and safety. However, the path will traverse the side slope of the water fall for an estimated 663 feet.

Thrust Blocks

In large piping systems with high flow rates and/or high pressures, thrust blocks are often used at bends in the piping in order to brace the system against the force associated with directional change of flow. In this system, the thrust force due to the fluid changing direction was calculated for each anticipated bend. This analysis, explained in greater detail in Appendix D-Penstock, allowed the Team to determine what size thrust blocks are needed at each of the major bends, as summarized in Table 3.

Table 3: Thrust Block Design for Upper and Lower sections of the Penstock, as defined by midpoint in elevation

Location	Magnitude of Bend	Thrust Block Weight (kg)	Thrust Block Volume in Concrete (m^3)	Thrust Block Volume in Rock Gabions (m^3)
Upper Section	45 degrees	1281	0.53	1.02
	90 degrees	5110	2.13	4.09
Lower Section	45 degrees	2318	0.97	1.85
	90 degrees	9233	3.85	7.39

As indicated in Table 3 the thrust block can either be constructed with concrete or with rock gabions. For concrete, forms can be erected around the corners of the indicated bends and the concrete can be poured to incase the corners. A cost saving alternative to concrete is erecting rock gabions. These can be constructed with local rocks and rebar and wire meshing. The weight of the rocks will have the same effect as concrete.

Figure 6: Example of Rock Gabion
Photo by Geota [4]

The large thrust blocks needed, especially at the 90-degree bends, indicate that the penstock should be constructed to minimize these bends. By using two 45-degree bends in the place of a 90-degree bend, the size of the needed thrust blocks would be reduced by 50%. Forty-five degree bends also help to reduce headlosses within the system.

Anchoring

The anchoring of the penstock to the ground, especially when traversing steep declines, is also important. Anchoring points should be located every five feet along the penstock path. Eighteen inch holes will be drilled into the rock on either side of the pipe at each of these anchoring points. Bent rebar pole will be placed over the pipe, with the ends going into each of the holes. Concrete will then be used to fill these holes and hold the rebar in place. An example of such anchors can be seen in Figure 7. The thrust blocks will provide additional stabilization.

Figure 7: Rebar Anchors
Photo by Domes [5]

3.4 Housing

The housing unit will hold and protect the turbine, generator, gear box and other electrical parts. Zapatero suggests having a slab concrete floor, wooden support column, wooden sides and a plastic corrugated roof. A model of this housing can be found in Figure 8. This housing structure will be placed near the waterfall but out of the flood plain. A picture of the location selected by the team is seen in Figure 9. More details on the selection of the site for the power generation house can be found in Appendix E- Generator Site Selection. Design aspects of the generator housing can be found in Appendix F-Housing Design.

Figure 8: Model of generator and turbine housing.
Model by Andrea Walvatne

Figure 9: Generation Site in relation to the Zapatero River
Picture by J. Cole

Tail Race

The tail race is the diversion structure that directs the spent water from the turbine to the river. The housing unit will be built to accommodate this channel beneath the turbine. The tail race design includes considerations about the size rock being used for construction, the angle of repose, and side slope angles. By utilizing the method by Sturm [6], a critical velocity was found for the flow rate coming from the turbine, and this was utilized along with shear stress analysis to ensure the channel would convey the design flow rate without collapsing or scouring. The resulting design suggests using rocks with a 10 cm diameter, an angle of repose of the riprap of 41° and a side slope angle of 23°. A cross-section of the tailrace can be seen below in Figure 10. It should be noted that the normal height of the flow was determined to be .87 ft., and increasing the channel depth to 1 ft. was done to allow for a factor of safety. The full analysis can be found in Appendix G-Tail Race Design.

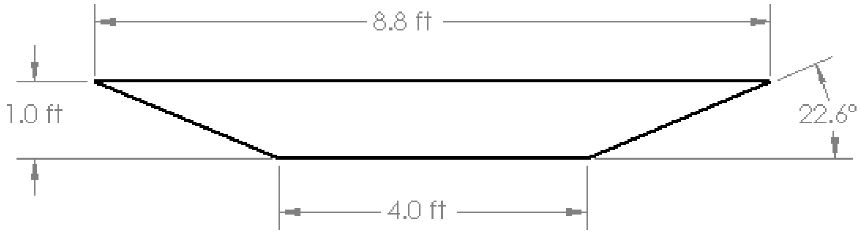


Figure 10: Tail Race Design Cross-Section

3.5 Turbine

The turbine is the core device in a micro-hydro system for turning the energy of a waterfall into electricity. There are many different kinds of turbines which can be employed in micro-hydroelectric systems. Most of the turbines can be categorized as impulse or reaction turbines. Impulse turbines function as a wheel that spins due to water impacting buckets or fins. Reaction turbines spin by capturing the pressure going through the system. There are advantages and disadvantages for both. After weighing both options, the Team decided upon an impulse turbine, more specifically a cross flow turbine. A picture of one can be seen in Figure 11. This design has advantages of being less expensive, easier to transport and install, and fewer problems associated with cavitation compared to impulse turbines. There are some disadvantages to cross flow turbines, including the lower efficiency and the need to have a consistent flow. The Team was in contact with a company in Washington, Canyon Hydro, which sells small hydropower systems. The Team decided to design with Canyon Hydro's systems in mind, one of which is pictured in Figure 12. In Appendix H - Turbine and Power Calculations, a list of calculations can be found for the different aspects of the turbine design.

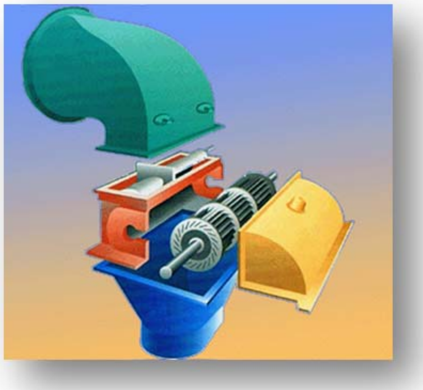


Figure 11: Example of a cross flow turbine set up and housing [7]

Figure 12: Canyon Hydro Cross Flow Turbine Picture Taken by Eric Melander [8],

3.6 Generator

The generator that will be employed is a synchronous machine produced by Marathon Electric. This generator model, 362PSL1604 is designed to continuously produce 84 kW of power at 40 degrees Celsius. The machine will supply 480 Volts and rotate at 1800 rotations per minute. A specifically designed gearing system from Canyon-Hydro will step-up the rotations from the turbine to the generator. The device is 3-phase at 60 Hertz which produces more consistent power than a single-phase system. The net weight of the Marathon generator is 943 pounds, (428 Kg) and obtains a footprint of approximately 2.6 x 1.6 ft. (80 x 50 centimeters). Marathon Electric generators are commonly employed in developing communities worldwide due to their cost effectiveness as well as their low maintenance requirements [9]. Six bolts will secure the generator to the concrete floor of the housing structure to minimize movement and prevent vibrational damage. The exact generator is displayed below in Figure 13 and generator parts and specifications are given in Appendix I – Generator.

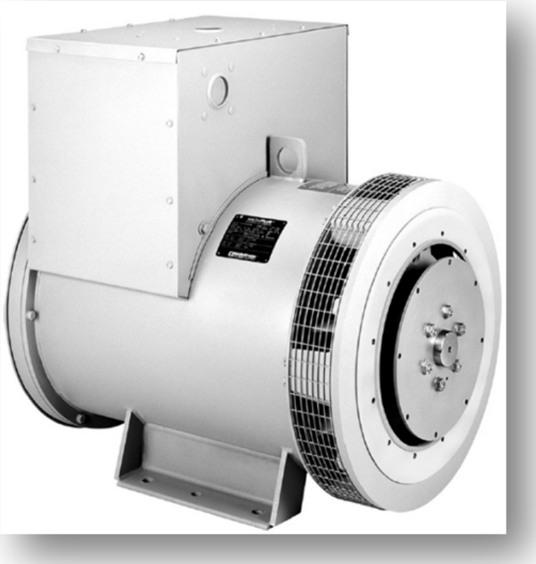


Figure 13: 362 Marathon Electric Generator [10]

3.7 Transmission

The power transmission system is comprised of several different components. A simplified depiction of the entire system can be seen in Figure 14. Immediately following the turbine, the electricity will transfer through a KA Frame 480/240 Volt circuit breaker. This will act as an emergency shut-off to stop the transfer of power through the transmission system. The circuit breaker will be attached to an Allis Chalmers 4160 Volt transformer. This transformer will increase the voltage and thus maximize the amount of power that will be available after transmission. The exact specifications for both the circuit breaker and transformer are displayed in Appendix J-Transmission. Both of these components will be located within the generation house near the turbine and the generator.

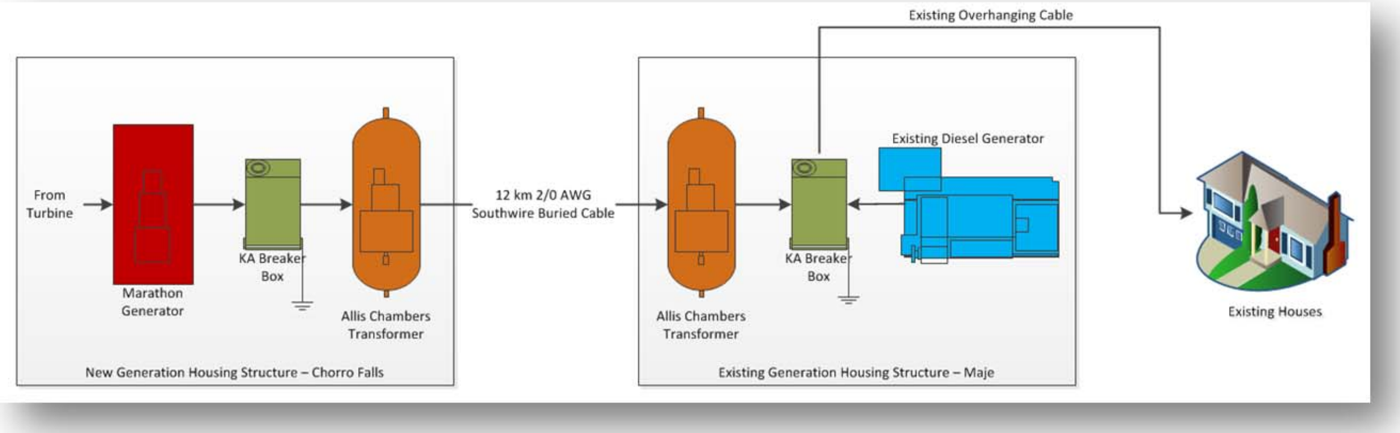


Figure 14: Overview of Power Transmission System
Model by Tyler Losinski

A 2/0 AWG insulated aluminum wire produced by Southwire® will transmit the electricity from Chorro Falls to the community of Majé. The cable will be buried 15-18 inches deep into the ground along the seven mile (11 km) path. When a river crossing is encountered, the transmission line will be housed in a 1.5-inch-diameter schedule 40, PVC pipe. This conduit tubing will be suspended at an appropriate height above the river to ensure that the line and supports are out of the flood plain. The pipe will be supported by overhanging cables and wooden towers on each bank of the ravine.

Within the community, the power transmission cable will be attached to existing power poles and suspended above the ground. The power line will be directed to the existing diesel generator facility. Within the housing, the line will be connected to an Allis Chalmers step-down transformer to bring the voltage to 240 Volts and then an additional KA Frame circuit breaker. This breaker box will be located on the exterior of the house to ensure for easy access.

Approximately 1.7 kW is lost in the transmission of the power due to resistance that occurs within the cable. At the end of the micro-hydroelectric system, 78.4 kW of electricity will be supplied to the community of Majé. Complete power calculations are given in Appendix J - Transmission.

4.0 Cost Estimate

The estimated total cost of the proposed micro-hydroelectric system is $476,600. The detailed breakdown for this estimate is outlined in Appendix L - Cost Analysis. The analysis is divided up into main components that also correspond to the construction schedule which can be found in Appendix K – Construction Manual and Schedule.

As seen in Table 6 below, the first section accounts for the mobilization of equipment and materials that will be shipped from Chepo and Panama City by truck or boat. The mobilization costs will account for approximately $8,000. The second section accounts for the total cost of the inlet and forebay construction. The construction materials and equipment costs for this component will be about $2,000. The third section accounts for the penstock construction which accounts for $37,000 of the total cost. The biggest expenditure for the penstock is the PVC pipe because of the large diameter needed. The third section is the construction of the housing for the turbine and generator, which will cost about $3,900. The fourth section accounts for the turbine, generator, and power distribution, which accounts for the majority of the total cost at $373,500. The turbine itself is $100,000. The cost of skilled labor and a professional engineer were taken into account with this estimate, but all other general labor is assumed to be provided by the community at no cost.

Table 4: Cost Estimate

Category	Total Cost ($)
Mobilization	$ 7,595
Inlet/Forebay	2,022
Penstock	37,170
Housing	3,909
Generator /Turbine	276,776
Power Distribution	96,720
5 % Error	$21,210
Total Cost	$ 445,402
including 7% tax	$ **476,579**

5.0 Construction

Zapatero Engineering prepared a construction schedule and construction guide for the community of Majé Chimán.

Schedule

The full construction schedule can be found in Appendix G -Construction Manual and Schedule. The construction is scheduled to take approximately two years. There are many aspects that contribute to the long construction time, including the short dry season of Majé Chimán which spans from the beginning December through the end of March. There are certain tasks, such as generator housing construction, that were purposefully scheduled for the dry season. There is the potential to need to shift the construction schedule more if the community finds it difficult to complete aspects of the design that are scheduled during the rainy season. This construction schedule was made with consideration of the difficult construction terrain of the area and the lack of modern amenities.

The schedule shows the first task is construction of a path to the generation site. This path is a vital portion of the project since much traveling and hauling of material will be done from the community to the generation site seven miles (11 km) away. The housing is listed as the next construction task to be completed, since once the housing is built, materials for the rest of construction can be stored there and the workers can use it as shelter, optimizing their time available to spend on construction. Next the penstock, forebay, and hook up of the turbine and generator will be completed. The installation of the turbine and generator will need to be completed by professional and skilled laborers, as this installation is likely beyond the abilities of the community members.

Labor

As stated previously, there are no manual labor costs associated with this project because the work will be completed by community members. A professional engineer and skilled electrician are accounted for in the final cost analysis and will be utilized for their expertise in certain aspects of construction and implementation. The construction schedule allots more time for the construction activities then would be needed in a modern construction schedule because of the labor constraint and lack of modern equipment. The men working will not be a full time crew, but rather they will take time off from their daily duties and volunteer their time. It is expected that the work crew will vary day to day as different men are able to commit time to the project on a daily bases.

Construction Suggestions

Zapatero has provided a detailed construction manual in Appendix K- Construction Manual. This guide explains, in greater detail, each of the major aspects of construction outlined here.

Prior to the actual construction of the micro-hydroelectric power system, the construction workers need to make preliminary estimates to ensure correct planning has been done for the project and the correct amount of material is ordered. The jungle terrain outside of Majé Chimán makes the transportation of large pipes, construction materials, a generator, and turbine difficult. Therefore a path will need to be initially constructed that traverses the seven miles (11 km) in order to complete the project. This path needs to be approximately two and a half meters wide. The path should be built with a slight down grade from the centerline leading water to the sides of the road.

The housing for the generator needs to be the first aspect built after the construction of the path. This housing will be used for storage of material and for human shelter. The suggested housing design is a concrete slab floor, wooden support columns, wooden sides, and plastic corrugated roof. After the housing is built, the penstock pipe will then be laid and connected in place. Then at the 45°and 90° bends, concrete thrust blocks need to be constructed. The piping will have extra support along the path held in by re-bar bent into U shapes and inverted over the pipe into bore holes 18 inches deep on either side. The penstock needs to be constructed before the inlet but consideration of where the ideal forebay structure location should be made before penstock path is finalized. The diversion structure will be a rock gabion wall in the middle of the river. One half of the river will continue downstream but the other half will be diverted to a man-made channel into the forebay by this rock gabion. The rock gabion will be metal meshing filled with rocks supported by rebar at the corners. The forebay structure is a made out of poured concrete with rebar supports. The top of the forebay will be protected by a corrugated plastic sheeting roof. This cover will be elevated just enough to allow water to overflow from the forebay in case of flooding.

The generator and turbine hook up will need to be completed by a skilled laborer. The transmission line will run the seven miles (11 km) from the generation site to the community of Majé. The transmission cable has adequate insulation that allows the line to be buried directly into the earth. In accordance with the National Electric Code, the cable will be buried to a depth of 15-18 inches. There exist seven river crossings. At each crossing, the transmission wire will be incased in a schedule 40, 1.5 inch diameter PVC pipe. This pipe will then be suspended in the air by employing wooded base structures as well as overhanging cable that is attached to surrounding trees.

Maintenance

Zapatero Engineering also created a maintenance document for the community. It was important to address maintenance with the community because the system is seven miles (11 km) away, and weekly inspection will need to be conducted as well as more thorough yearly inspections. This means considerable time and effort by the community to ensure that the system continues to run well. The community has established committees such as a water committee, and it is Zapatero's suggestion for the community to create another such committee for the upkeep and maintenance of the micro-hydroelectric system. Electricity usage charges will need to be strictly enforced to cover maintenance costs. Even if the community was awarded a grant for the initial investment, there are substantial costs associated with upkeep and maintenance. Currently the community pays twenty cents an evening, or approximately six dollars a month, for access to limited hours of power. Based the knowledge of household incomes the Team expects the community to be able to pay ten dollars a month for 24 hour electricity. This would provide just under $14,000 per year for maintenance funding. A full maintenance scheme can be found in Appendix M- Maintenance.

5.1 Environmental Impacts

Zapatero's goal is to have no significant environmental impacts imparted on the community's pristine area as a result of the micro-hydroelectric construction. The Team believes that there will be no serious environmental consequences as long as certain precautions are followed.

The Panamanian Government has environmental regulations. But the level of enforcement has varied over time and by location. According to the Interamerican Association for Environmental Defense (ADIA), these new change in Panamanian government allow some development projects such as dams and mines to proceed without the preparation of environmental impact assessments [11]. The ADIA has expressed concern that Panama is moving forward on large-scale development projects that are "in violation of the international and domestic human rights and environmental laws" [11]. While these reports are troubling, it also indicates that the project proposed here may not require a formal environmental impact assessment reviewed by the government.

Nonetheless, considerations will still be made to make sure this project is completed in an environmentally sound manner. One such consideration was using no more than half the Zapatero River's flow and returning the water to the river once it has been used. By allowing at least half the river to stay the course, it reduces any impacts on aquatic life, and returning the water makes downstream impacts negligible.

One major concern of construction is erosion. A significant path is to be constructed from the community to the generation site. This path construction will include removing trees and clearing brush, and will facilitate significant travel on the walkway. These compounding effects could cause erosion of the underlying clay. The biggest concern related to erosion would be increased turbidity of the water in the Zapatero River, which is often the water source for the community. To mitigate this erosion, the path will be constructed with small ditches on either side to convey water away from the path. In these small ditches, at every one-eighth kilometer increments, a small stone pile will be constructed to reduce flow velocity and collect part of the soil eroded from the path. Also, the large size of this watershed reduces the effect of erosion from this path. Once the construction has been completed, the high traffic along the path will diminish and the ground cover will naturally come back to the path. While the path needs to be preserved for maintenance purposes, it does not need to be as easily traversable as it was for construction and the transportation of equipment.

6.0 Alternatives

There are other alternatives to micro-hydroelectric power for the community of Majé Chimán. In order to assess these alternatives in comparison with the micro-hydroelectric system proposed, an approximate cost analysis was performed on each alternative.

Three alternative options were investigated. The first is running the community's current generator for sixteen hours a day, the second is providing each home with a small solar panel and the third is connecting to an already established electrical power system. These options were chosen based on the need and want for consistent power. More detailed methods and explanation of assumptions made to determine the cost estimates can be found in Appendix N - Alternative Analysis. Maintenance of the proposed alternatives was ignored in the analysis. The cost associated with each of the alternatives is summarized in the Table 5 below.

Table 5: Cost Analysis of Power Source Alternatives

Alternative	Cost
Running Diesel Generator for 16 hours a day ($/year)	**$127,000**
Solar Panel on each home in the community ($)	**$171,000**
Connecting to Existing Infrastructure ($)	**$191,500**
Micro-hydroelectric Design ($)	**$476,600**

The cost of the micro-hydroelectric system is the largest, but there are aspects to each of the other alternatives that outweigh their cost savings. The diesel generator may be one third the cost of the micro-hydroelectric design, but the cost shown above would be a reoccurring cost the community would have to bare each year. If the cost of three years running the diesel generator was put toward the hydroelectric design, the community could have comparable energy for five to ten years, potentially even longer.

The solar panel option would not have the reoccurring cost of the diesel generator option and is significantly cheaper than the micro-hydroelectric power. The downfall to this option is that the panel would not provide enough energy to each home to meet their expressed electrical aspirations. These panels only provide enough energy to charge a battery that can be used for lights and small appliances, such as televisions.

The option of connecting to the existing infrastructure would need further investigation before ruling out. The capital cost is lower than the micro-hydroelectric system but the fee for usage is unknown. If the costs are reasonable and less than the expected maintenance costs of the micro-hydroelectric system then this option could be a better alternative.

The micro-hydroelectric system could still be the best option for the community after further investigating is done as mentioned above. An advantage of the micro-hydroelectric system is once the initial capital cost is invested, the system can provide the community with a large amount of power for many years with minimal reoccurring costs, aspects that the other options lack.

7.0 Community Aspects

Any well thought-out engineering design considers the impacts on the users and the ability of the users to support that system.

7.1 Social Impacts

Bringing nearly 80 kilowatts of power to the community of Majé Chimán will significantly impact the lives of the villagers. Some of these social impacts will be positive while others may be negative, and it is an ethical responsibility of Zapatero Engineering to analyze both sides.

Twenty-four hours of consistent energy can improve the lives of these villagers. The women would have access to washing machines which would reduce the time spent in the river washing clothes. The women could also switch to modern stoves or burners which would decrease the amount of cooking done on wood fires indoors, thus improving indoor air quality. The men could use power tools and increase production of their wood carvings, resulting in an increase in income. Lights at night could be employed so homework, weaving, carving could all be done after the sun goes down. This would create more income, better education and more opportunities for advancement. The community would be able to use their computers in the school, keep medicines and vaccines chilled, and

Figure 15: Women Washing Clothes in Majé Chimán
Picture by J. Cole

receive communication from outside of the community. In addition, eco-tourism is an avenue the community wants to pursue which would be dependent on providing a consistent power source for visitors, which this project could provide. These impacts all mean improving the lives of the Wounan people.

There are also negative social impacts that Zapatero foresees with the implementation of this design. The Team feels that it is their duty to provide education about these aspects to the community so that they can determine if the positives outweigh the negatives. Zapatero Engineering noticed that the women often wash their clothes together in the stream as seen in Figure 15. Having washing machines in each of the homes would break this social interaction and may cause women to feel more isolated. One suggestion is creating a public "laundry mat" where the women can still interact and have that social aspect but have the modern amenities as well. Also, community owned and operated irons and washing machines make the endeavor more economically feasible.

Zapatero Engineering would also be concerned about the loss of culture. As the community becomes more modernized, there may be a shift from spending time participating in traditional stories, dances and other cultural aspects to time spent watching television, listening to the radio, or playing games on their phones and computers. The Team has had firsthand experience of the rich culture of this area and wants the community to realize what a treasure it truly is.

7.2 Energy Saving Opportunities

The power delivered to the community is not going to be the 100 kilowatts the Team was aiming for. This is due to headlosses in the penstock, the efficiency losses of the turbine and generator, and resistivity losses in the transmission lines. Even though the design power output is now 78.4 kW, the Team believes it will be sufficient for the community's growing electrical demands especially if some simple energy saving alternatives are followed. Through analyzing the survey data from the community regarding their electrical aspirations, the Team compiled power usage statistics as can be seen in Figure 16. As seen in the figure, the irons contribute to the highest peak rate, exceeding the system capacity. Figure 17, on the other hand, shows the hourly power usage if some of the appliance usage has been distributed over the day and energy saving opportunities are employed, such as laundry mats. The peaks are then below the capacity of this system. More details on this analysis can be found in Appendix O - Energy Savings.

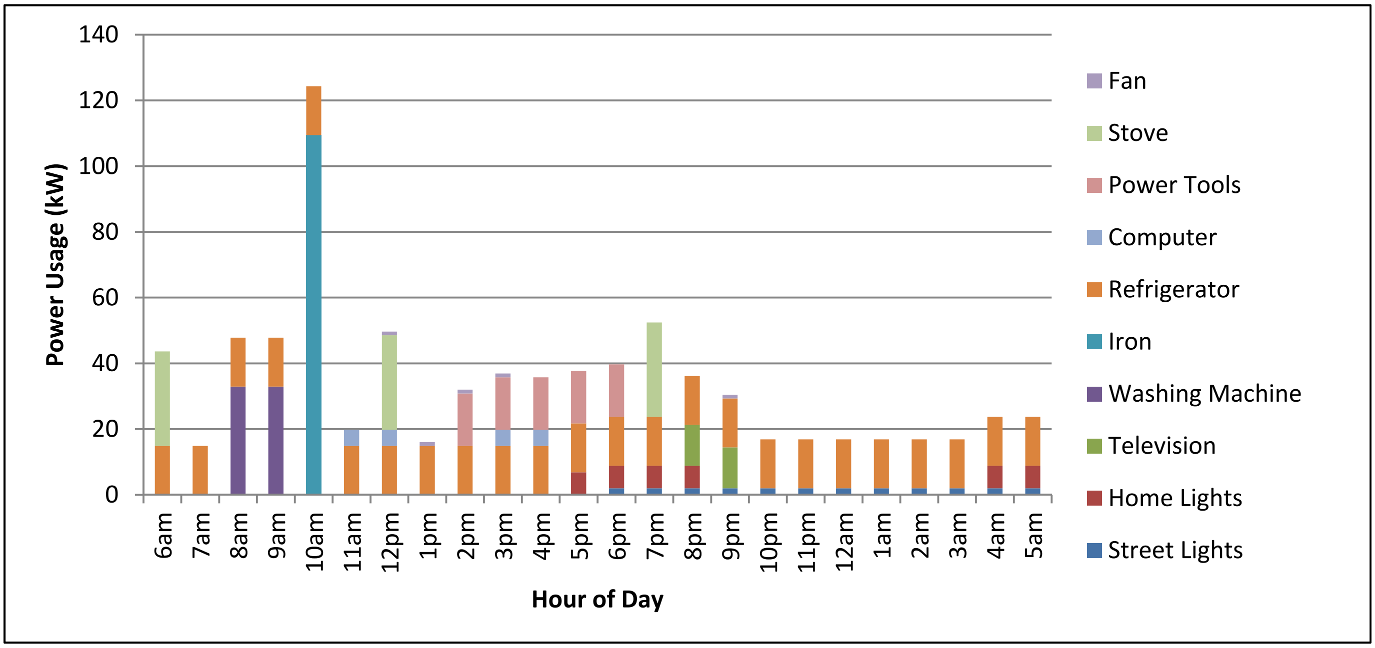


Figure 16: Community Power Demand Survey Results

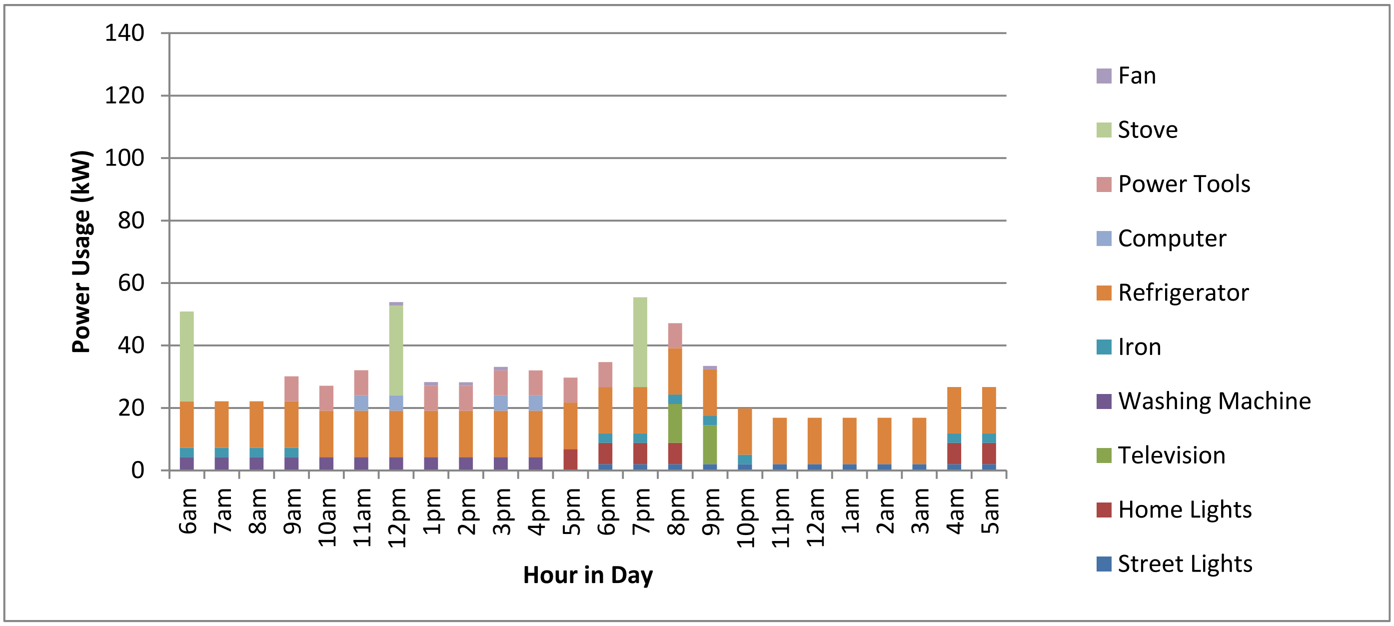


Figure 17: Alternative Schedule for Appliance Use

This is a proposed plan and it is up to the community to make sure their members are following this plan or a similar one prepared by them. As the community grows, they need to be cautious with the amount of energy they are using and how to schedule the use of higher energy consuming appliances. They also need to understand the level of organization that this project would involve. The community members seemed very excited about this project and organized in other observed activities, so the Team believes this is within their capacity.

7.3 Electrical Safety and Education

It is to the upmost importance that Zapatero Engineering takes electrical safety into consideration when designing the system. Due to high power output of this hydro-electric system, it is strongly recommended that all electrical components are installed and inspected by a licensed professional electrician. In addition, all maintenance that requires the manipulation of any electrical mechanisms should be completed by a trained professional. Human death occurs if one comes into contact with either high voltage or a current that is over 0.8 amperes. The proposed system has both of those factors, with a voltage of 4160 V and 20.8 amps. Therefore education of the community of the potential dangers of this system is extremely crucial. It was noted that anyone could potentially walk into the current generator house within the community and access the system. The Team suggests that it be locked and only accessible to members of the electrical committee that understand the risks of an electrical system. Also, with the newly cleared pathway to Chorro Falls, visits to the falls will be more frequent. It is recommended that the generator housing at the waterfall be only accessible by community members that understand the risks of power generation since there are dangers from the spinning turbine blades and the electricity being produced in the housing.

In addition to safety, engineering controls will be installed to promote electrical safety. Two large KA Frame circuit breakers will be installed for emergency shut-off. One circuit breaker will be installed between the generator and the 4160 V transformer in the generator housing near Chorro Falls. A disadvantage of this is that a person will have to travel the 11 kilometers in order to cut the power in the transmission lines. Therefore, Zapatero Engineering also recommends a KA Frame circuit breaker between the transformer and the community hookup located in the diesel generator housing. This position is much more centrally located and will allow the community members to cut power to the village quickly if an emergency were to occur. In addition to the circuit breakers, grounding wire is planned to be installed in the both transformer locations as well. This will send any excess electricity into the ground, reducing the chances for arcing to occur within the system.

7.4 Funding Opportunities

Zapatero realizes that the high price tag of this design makes it a far reach for this community of artists and subsistence farmers. The Team hopes that with the design work completed the community can go forward and use this information to seek funding opportunities. The Team believes that their design can help the community justify to organizations and the government that there is a potential for power from this waterfall.

AES Changuinola is a private company that has designed micro-hydroelectric systems in developing areas of Panama. The Team believes this company may be able to provide leads about funding opportunities as well as recommendations for designing a system for a remote area.

Small Hydro Latin America is an annual conference that took place in Panama City, Panama, on the 5th and 6th of December 2012. This conference hopes to increase the utilization of micro-hydroelectric systems. This is a two-day event that is geared towards providing information about these systems, as well as providing a place for networking and enhanced business opportunities. Next year's conference would be a great opportunity for this project to be seen by groups that could potentially provide funding. The organizer of the event, Eduardo Vallarion, has been contacted and the Team is awaiting a reply.

While in country, the Team also witnessed the governmental projects that had already been installed in the community, such as the existing electrical system, side walk system, and the water distribution system. While the community has expressed that the current government is not as concerned about the village of Majé as past governments have been, there is an election occurring in the country within the next couple of years. This may be a good time to show these designs to the current government, who may be looking for ways to increase their popularity for re-election. There may also be opportunities to show the plans to a new elected government if there is a change in office.

8.0 Feasibility and Design Validation

8.1 Project Feasibility

The feasibility of a project of this magnitude rests on many aspects including cost, location, and community capacity for construction and maintenance.

Location

The location of the system does add a degree of difficulty. The transportation of materials to the location of construction will take significant time and effort. The material must be shipped into the community during the dry seasons since this is the only time in which trucks can access the community, and boat transportation of much of the construction materials would be difficult. Also, the materials need to be transported up the mountain trail to the generation site seven miles (11 km) away. This will be difficult especially with the turbine and generator, which are heavy pieces of machinery.

Maintenance

The ability of the community to maintain the system is critical to its success. Zapatero does have some concern about the ability of the community to maintain the system because of the Team’s observations while in the community. The current electrical system, while working, has utilized three different generators over the 15 years since implementation. When one of the generators broke instead of fixing it, the government brought in a new generator. In the case of the micro hydro system, the ability for the machinery to last for many years makes it cost effective. If the community is unable to maintain the system or fix problems as they arise, however, the system will quickly fail and the efforts will become futile. As mentioned in the maintenance section, the maintenance is time intensive because of the long distance between the community and the project. The men in the community are busy and spend many hours each day working, and it will be necessary for many men to share the duties of upkeep for this system. While the community may have had past issues with maintenance of the other system, Zapatero believes that the community could maintain the system if the correct education and training was provided to the community.

Construction

The feasibility of construction rests on the ability and willingness of the community to seek out professional and skilled labor. While the community members are proficient builders there is an expertise, which can only be provided by a professional engineer, which would be needed to guide the workers. This professional would need to be able to make site visits and keep up with the construction process. Also, skilled labor would need to be employed to install and connect the turbine, generator, and transmission lines. Zapatero Engineering feels that a majority of the construction could be completed by the community members such as housing, inlet and penstock construction, and everything else could be completed with professional and skilled labor.

Economics

The community also needs to be conscious of the financial responsibility that comes with this project. Zapatero Engineering realizes that the community does not have the capacity to front the capital costs of this system. Suggestions for funding opportunities can be found in the Funding Opportunities Section. The Team does believe that the community has the capacity and needs to be able to fund the cost of maintenance in order for this project to succeed. This means that each household that uses electricity will need to contribute financially. The Team conducted surveys throughout the community and found that some households were paying for the electricity while others could not afford or chose not to pay the fee. A more in-depth study would need to be done on household's ability to pay for electricity to confirm the community could financially support the costs of maintenance.

8.2 Evaluation of Design Objectives and Constraints

Zapatero Engineering made some preliminary goals for objectives and constraints upon returning from their assessment trip. Tables 6 and 7 display the actual values along with a column showing if the objective or constraint was actually achieved based on the final design.

Table 6: Validation for Project Objectives

Priority Rating	Method of Measurement	Objective Direction	Target	Actual	Objective Met
4	Total System Cost	Minimize	$150,000	$476,000	No
2	Cost of Professional Labor	Minimize	$15,000	$80,000	No
3	Cost and Time	Minimize	10% of System Cost	N/A	No- 3% of Total System Cost
2	Turbidity Measurements Down Stream	Minimize	10% Increase of Current Turbidity	N/A	Unknown
4	Available Watts in Community	Maximize	100 KW	78.4 kW	No

Table 7: Validation for Project Constraints

Constraint	Method of Measurement	Limit	Constraint Met
Safety	Number of Injuries/Deaths	0	Unknown
Available Head	Surveying and Head Loss Calculations	30 Meters	Yes
Water	Measure the Zapatero River Flow Rate	1 Cubic Meter per Second	Yes
Location	Distance From Community	11 Kilometers	Yes
Installation Timeframe	Months Required to Install	3 Months	Yes

Looking at the two tables it can be seen that there are many objectives that were not met, but almost all of the constraints were. This is due to the fact that the Team wrote the objectives and constraints out when they returned before the design work was initiated. The design processes lead the Team to realize they had misjudged the magnitude of the overall project.

For example, the cost estimates at the beginning were lower than the final calculations because the Team did not know about some of the components that would be necessary, how expensive some of them were, or the amount of material needed. The Team made estimation on the economic capacity of the community for maintenance funding and since the total system cost was higher than expected this economic support is much less than 10% of the system costs the Team original reasoned. In this table the one unknown is due to measurements that would need to be taken after implementation. The power supplied to the community was decreased because of the calculated losses in the system, but the Team believes that 78.4 kW would be enough for the community's needs as discussed earlier.

The constraint for safety is unknown because this too would be measured after implementation. The rest of the constraints were met. The timeframe was also met because while the Team organized the construction to take two years' time it was scheduled with the dry season time frame in mind.

9.0 Study Limitations

It is important to identify the limitations of the study and design brought forth in this report. Throughout the Fall 2012 semester the Team had to design around limited data, limited knowledge and time constraints. Zapatero Engineering would like to indicate that this report should be referred to more as a feasibility study and in order to proceed with this design a more in depth study by professionals is recommended.

Data Limitations

The data collected by Zapatero Engineering was limited. The seven miles (11 km) of mountainous terrain between the community and the waterfall made it impossible for the team to haul precision survey equipment. For this reason simpler tools were used, such as Abney levels and a bottle and string, to collect information about the water fall. Although Zapatero Engineering used the available equipment correctly, there exists a possible larger margin of error associated with the equipment used compared to precision survey equipment. Also, due to the language barriers, pertinent information could have possibly been lost due to the three linguistic translations that existed. The Team also had limited amount of time available to spend at each waterfall. To ensure the safety of the Team, it was required that both expeditions to the waterfalls be completed in daylight only allowing for approximately one hour at each waterfall.

Since the Team had no way to obtain data after leaving the country, any aspect encountered during the design that needed additional data was completed with assumptions, such as the penstock path. The penstock path was not mapped out by the Team in the short amount of time the Team was at the waterfall therefore the length and path of the penstock was estimated to complete the design.

The Team also encountered difficulties when completing the cost analysis. Price gauging was completed at a local store while in community but this provided to be of limited help. Most of the cost estimates were from American suppliers and an equivalence assumption was used for prices in Panama. This could be a significant source of error in the cost estimate.

Knowledge Limitations

All members of Zapatero Engineering are students of various engineering disciplines and their work should not be regarded as professional engineering work. The Team worked under the guidance of more senior engineers but the design here is solely the work of engineering students. For this reason there may be aspects of the design that a more experience engineer with a larger knowledge on such things might change in order to optimize the system.

Time Limitations

Time was a limiting factor for the team especially when considering alternatives. Having one semester to complete the design constrained the team to focusing on completing a full system design for micro-hydroelectric and not fully investigating alternatives.

10.0 Conclusions and Recommendations

Zapatero Engineering believes that the system outlined in this report could fulfill the electrical desires of the Majé Chimán community and increase the standard of living. This system has been designed to achieve 78 kW of power by utilizing 17.5 cfs of the Zapatero River's flow. An inlet structure of rock gabions will be constructed to convey the water to a channel directing water to the forebay. This 12ft x 12ft x 12ft forebay is key to keeping the water flowing through the 18 inch PVC penstock consistent. The penstock will traverse 670 feet to the generation site on which the concrete slab and wood sided generation house will be located. A 32 inch cross flow turbine will be located in this housing unit over the tail race channel, which will return the spent water back to the river. This turbine will be connected by a gearing system to a synchronous generator which will produce consistent power. The electricity will be transmitted by buried cable at 480 volts to the community seven miles away, where a transformer will step down the voltage for household use.

Hydro power is a renewable and sustainable option, but also an expensive one. While this system can provide a large amount of electricity, it will cost approximately $7,000 per kW. Zapatero recommends pursuing grants and donations to cover the capital costs of this system. The team also believes that community involvement and support for this system needs to be addressed before the project continues. The Team wants to emphasize that maintenance is going to be key for this system, and this maintenance will only be supported economically if the whole community is on board.

The Team believes the community should take the work provided in this report and use it to further pursue an electrical option that is sustainable and economical, whether that be micro-hydroelectric or another option.

11.0 References

[1] Drewyor, Watikins, Paterson. *Course Syllabus for CE4916 International Senior Design Project.* Michigan Technological University. Fall 2012.

[2] Williams, Arthur A. "Micro Hydropower." *AccessScience.com*. McGraw Hill, n.d. Web. 11 Dec. 2012.

[3] Joshi, Nirmal Raj. "Civil Structures Ghunsa Microhydro Project (GMP)." *Hydrological Stations of Nepal*. Wordpress.com, n.d. Web. 25 Nov. 2012. <http://nirmaljoshi.wordpress.com/2011/05/28/civil-structures-ghunsa-microhydro-project-gmp/>.

[4] "Gabion Cages." *Civil Engineering - Design and Supply*. Geotas, n.d. Web. 25 Nov. 2012. <http://geotas.com/pages/products/gabion-baskets.php>.

[5] "Anchoring Design." *Pool Domes*. Domerama, n.d. Web. 19 Nov. 2012. <http://www.domerama.com/types-of-domes/geodesic-pool-domes/>.

[6] Sturm, Terry W. *Open Channel Hydraulics*. 2nd ed. New York, NY: McGraw-Hill Copanies, n.d. Print.

[7] “Hydraulic Water Turbines.” Tripod. Web. 18 Nov. 2012. <http://members.tripod.com/hydrodocs_1/turbines.html>

[8] Canyon Industries Inc., *The Guide to Hydropower,* http://www.canyonhydro.com/guide/index.htm, 2004.

[9] Petrie, Edward M., Lee H. Willis, and Masaki Takahashi. "Distributed Generation in Developing Countries." *Local Power.com*. WORLD BANK GROUP, n.d. Web.

[10] *MAGNAPLUS: Power Generation for the 21st Century*. Marathon Electric, n.d. Web. 25 Nov. 2012. http://www.marathonelectric.com/generators/docs/manuals/GPN028.pdf.

[11] "Panama's Dangerous Road to Development." *AIDA Human Rights and Environment*. Interamerican Association for Environmental Defense, Apr. 2010. Web. 04 Nov. 2012. <http://www.aida-americas.org/en/project/panamasdangerousroad>.

[12] Ostermeier, Jerry. "Calculating Thrust-Block Size." *Renewable Energy & Efficiency Technologies*. Home Power Inc, 21 Feb. 2012. Web. 08 Oct. 2012. <https://homepower.com/>.

[13] Richter, Greg. "Lighting One House and a Few Smaller Buildings, Nationwide." Web blog post. *Shoal Creek Power & Light*. N.p., 2006. Web. 15 Oct. 2012. <http://gregrichter.com/scpl.html>.

[14] "HYDROPAK - Concept Design and Analysis of a Packaged Cross-flow Turbine." *Department of Trade and Industry Technology Program: New and Renewable Energy*. Department of Trade and Industry, Apr. 2004. Web. 15 Oct. 2012. <http://www.itpower.co.uk/files/pages/file/0793Hydropak-h03000780000.pdf>.

[15] *MAGNAPLUS: Power Generation for the 21st Century*. Marathon Electric, n.d. Web. 25 Nov. 2012. http://www.marathonelectric.com/generators/docs/manuals/GPN028.pdf.

[16] *Magnaplus Generator: 280-430 Frame Installation, Operation, and Maintenance Manual*. Marathon Electric, Sept. 2003. Web. 25 Nov. 2012. http://www.northern-lights.com/PDFs/manual_pdfs/SB504.pdf

[17] Mockmore, C.A. and Merryfield, Fred. 1.2 The concept of the Cross Flow turbine, Humanity Devel opment Library 2.0. <http://www.greenstone.org/greenstone3/nzdl?a=d&d=HASH019900853d74a507d7f400f6.4.3.pp&c=hdl&sib=1&dt=&ec=&et=&p.a=b&p.s=ClassifierBrowse&p.sa.> February 1949.

[18] Novák, Pavel, A.I.B. Moffat, C. Nalluri, and R. Narayanan. "Hydroelectric Power Development." *Hydraulic structures*. 3rd ed. London: Spon Press, 2001. 477-503. Print.

[19] Wurbs, Ralph Allen., and Wesley P. James. *Water Resources Engineering*. Upper Saddle River, NJ: Prentice Hall, 2002. Print.

[20] Duffy, Kyle. "The Importance of Proper Gauge Power and Ground Wire." *Sonicelectronix*. N.p., n.d. Web. 8 Oct 2012. <http://knowledge.sonicelectronix.com/view/printview-153.html>.

[21] "Generator End 35 KW Marathon Alternator 44 KVA MagnaPlus 283CSL1507 Generator End." *Crane Generators*. GENERAL POWER LIMITED, INC, n.d. Web. 15 Oct. 2012. <http://www.genpowerusa.com/35-kw-marathon-alternator-44-kva-magnaplus-283csl1507-generator-end/>.

[22] "SatCon PowerGate Plus S-Type PVS-110S 110 KW 480VAC Inverter." *Inverters*. CivicSolar, n.d. Web. 15 Oct. 2012. <http://www.civicsolar.com/product/satcon-powergate-plus-pvs-110s-110kw-480vac-0>.

[23] "Estimating Appliance and Home Electronic Energy Use." Energy.gov. U.S Department of Energy, 31 Aug. 2012. Web. 16 Sept. 2012. <http://energy.gov/energysaver/articles/estimating-appliance-and-home-electronic-energy-use>.

[24] MESA ASSOCIATES, INC, and OAK RIDGE NATIONAL LABORATORY. *Best Practice Catalog –Propeller/Kaplan Turbine*. Tech. U.S. DEPARTMENT OF ENERGY, 12 June 2011. Web. 16 Sept. 2012. http://hydropower.ornl.gov/HAP/MechKaplanPropTurbineBestPractice1.pdf

Cost Estimate References

Reference for all equipment, materials and scheduling except the ones mentioned below

R.S. Means Company. (2009). *RS Means electrical cost data*. Kingston, MA: R.S. Means Co.

[25] Inlet Structure Mesh
"Round Hole Mild Steel Perforated Sheet A36." *Stainless Steel*. OnlineMetals.com, n.d. Web. 21 Oct. 2012.

[26] Waterproof Epoxy
"Waterproof Epoxy Adhesive." *Epoxies*. Super Glue Corporation, n.d. Web. 21 Oct. 2012. <http://www.supergluecorp.com/super-glue/epoxies/waterproof-epoxy-adhesive>.

[27] Chain Saw
"Gas Chain Saw." *Hand Held Power Tools- Chain Saws*. Sears, n.d. Web. 21 Oct. 2012. <http://www.sears.com/poulan-33cc-2-cycle-14inch-gas-chain-saw/p-07135281000P>.

[28] Chain Saw Accessories
"Oregon 14 in Replacement Saw Chain." " Poulan Pro 3-Pack 32 oz Synthetic Blend Bar and Chain Oil". *Power Tools*. Lowe's, n.d. Web. 21 Oct. 2012. <http://www.lowes.com/pd_89297-422-S49-T_0__?productId=3061921>.

[29] Transformers
"Transformer 3309885 Allis Chalmers." *Allis Chalmers Oil Filled Transormer*. Midwest Electircal Testing and Maintenance Co., n.d. Web. 21 Oct. 2012. <http://www.swgr.com/store/Oil-Filled-Transformer/product/11-1340.aspx>.

[30] Shovel
"Truper Trunk Buddy Shovel." *Hand Gardening Tools*. Sears, n.d. Web. 21 Oct. 2012. <http://www.sears.com/truper-trunk-buddy-shovel-fiberglass-d-handle/p-07139592000P?prdNo=3&blockNo=3&blockType=G3>.

[31] Generator
"Generator End 35 KW Marathon Alternator 44 KVA MagnaPlus 283CSL1507 Generator End." Crane Generators. GENERAL POWER LIMITED, INC, n.d. Web. 15 Oct. 2012. <http://www.genpowerusa.com/35-kw-marathon-alternator-44-kva-magnaplus-283csl1507-generator-end/>.

[32] Turbine and Accessories
Canyon Industries Inc., The Guide to Hydropower, http://www.canyonhydro.com/guide/index.htm, 2004.

People References

- Eric Melander,
  Canyon Hydro Company
  5500 Blue Heron Lake
  Deming, WA 98244
  (360) 592-5552

- Ricardo L. Ortegon, P.E.
  Black and Veatch
  3550 Green Ct
  Ann Arbor, MI 49105
  (734) 622 8856

- John Lukowski
  Michigan Tech Electrical Engineering
  Office: 236 EERC of MTU
  (906) 487-2545

- Ed Hahlbeck
  Powertrain Engineers
  N3819 Round Hill Circle
  Pewaukee, WI 53072

12.0 Appendices

Appendix A – Community and Waterfall Mapping

Zapatero Engineering mapped several portions of the community and the surrounding areas with hand drawn maps and GPS way points. Figure 18 is a hand drawn map of the community which was utilized during the time within the community.

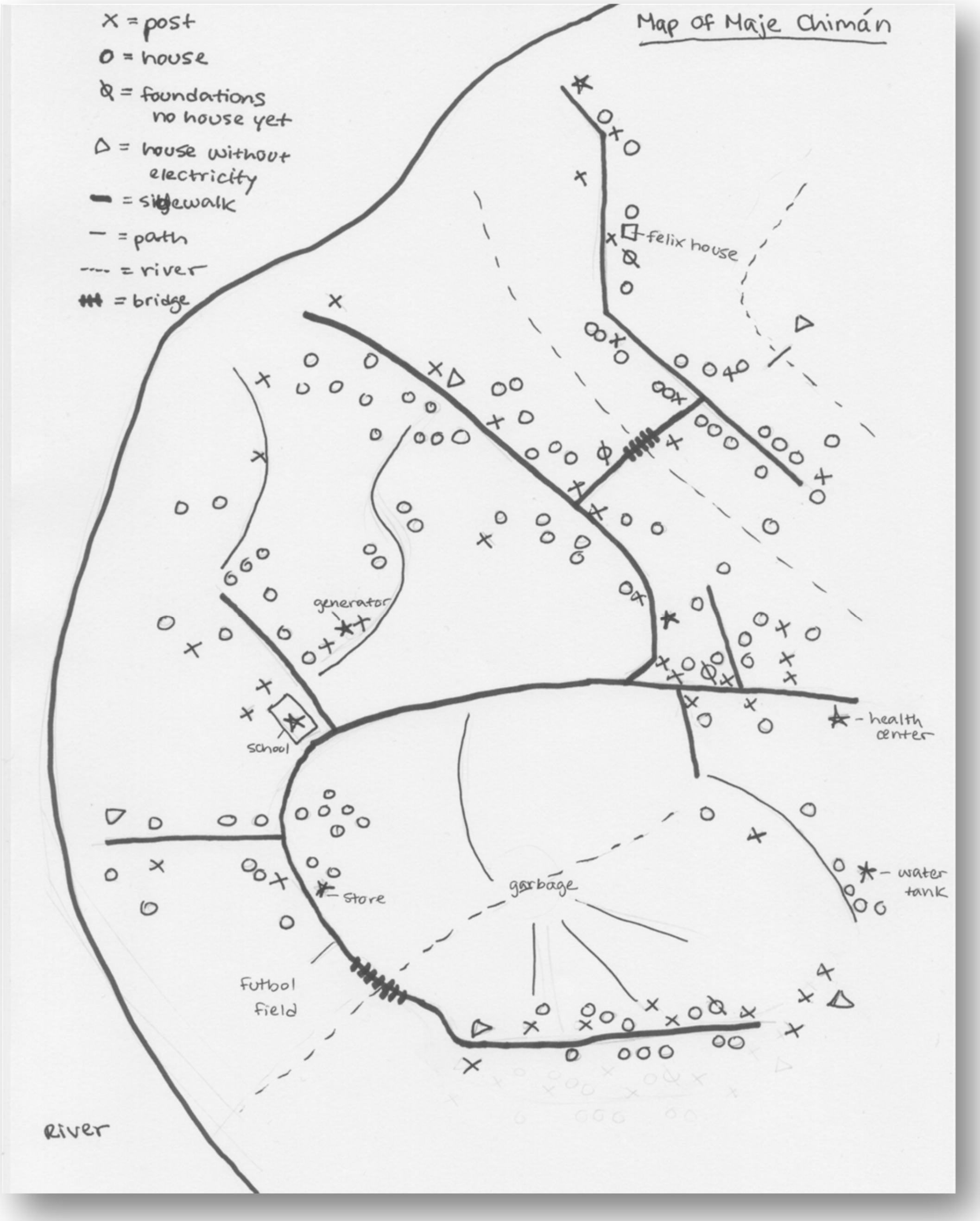


Figure 18: Map of Majé Chimán Community with major landmarks.

While in the community of Majé Chimán, Zapatero Engineering was also able to collect data about the current electrical infrastructure and data on potential expansion. The data was collected from within the community, while on the hike to the Chorro Fall, as well as at the Chorro Fall. The figures referenced below are maps compiled from GPS points. The maps were made using ARCGIS software. This software allowed Zapatero Engineering to utilize GPS coordinates in UTM projection and overlay them on topographic and satellite maps.

Within the community, the existing infrastructure was mapped, including electrical posts and light posts, which can be seen in Figure 19. The house where the Team stayed while in country (Felix's House) has been marked on the map as a reference point. The total cable in the community, based on the distances between light posts, is 4.8 kilometers.

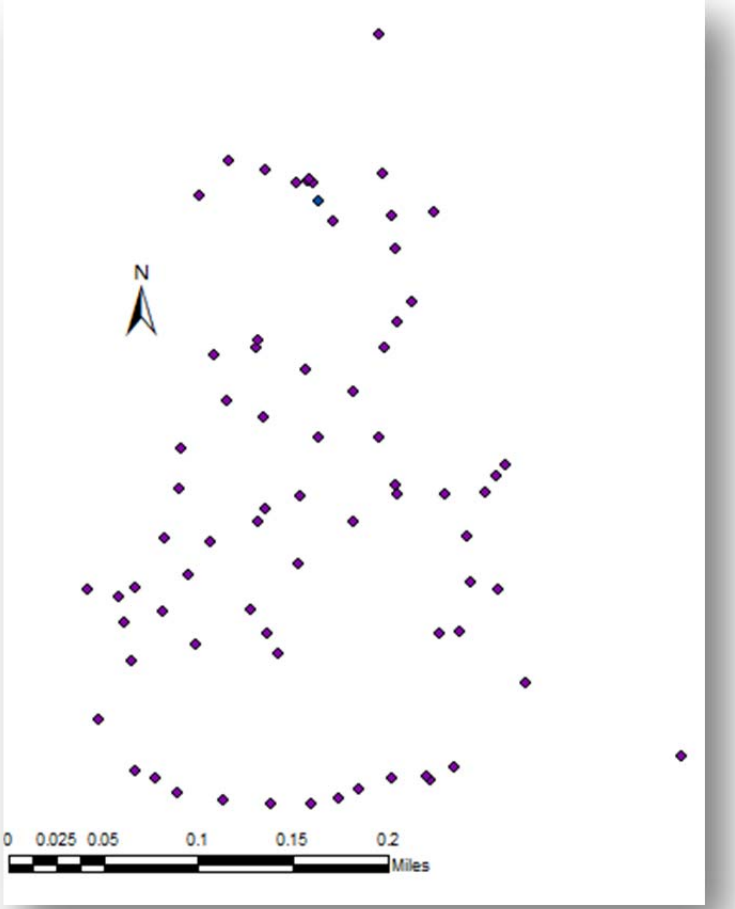


Figure 19: Community Mapping of Existing Electrical Posts

The data collected from the hike to Salto and Chorro Falls was minimal. Figure 20 shows the data points collected on a topographic map. Figure 21 shows the data points on a satellite image. A total of four points were collected on the path to the falls and multiple points were collected at each fall.

Figure 20: Topographic Map of the community and both waterfall sites.

Source: Esri, i-cubed, USDA, USGS, AEX, GeoEye, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 21: Satellite Image of community and both waterfall sites.

The first cluster of points to the northeast of the community on Figures 20 and 21 are points taken at Salto Falls. This specific data for Salto Falls was not analyzed in detail because it was determined that Salto Fall would not be able to satisfy the needs of the community. The more distant cluster is Chorro Falls. Chorro Falls has been selected as the site of the micro-hydroelectric power system.

Figure 22 displays a recreation of Chorro Falls to illustrate the actual distances from the falls to the two proposed generation sites. The distance from the base of the falls and the total height are used to determine the best generation site for this project. It is important to note that the river path was approximate but the specific points and the distances between them were transposes from ARCMAPPING software.

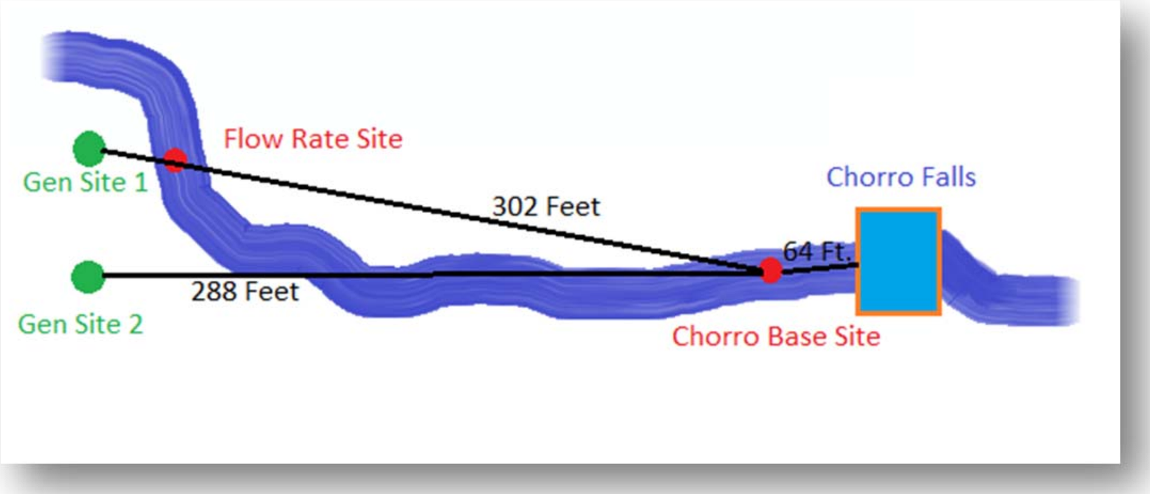


Figure 22: An approximate rendition of the Zapatero River with actual distances.

Figure 23 shows a map of Zapatero Engineering's journey from Panama City to Majé Chimán. The red line represents the three hour bus ride the Team took from Panama City to the port side town of Chepo. The second leg consisted of a 68 mile boat ride from Chepo to Majé Chimán. The part of the green line going into the Chimán region from the Pacific Ocean illustrates where the Team traveled the Zapatero River. The blue line is the recorded distance that the Team hiked to reach the waterfall sites.

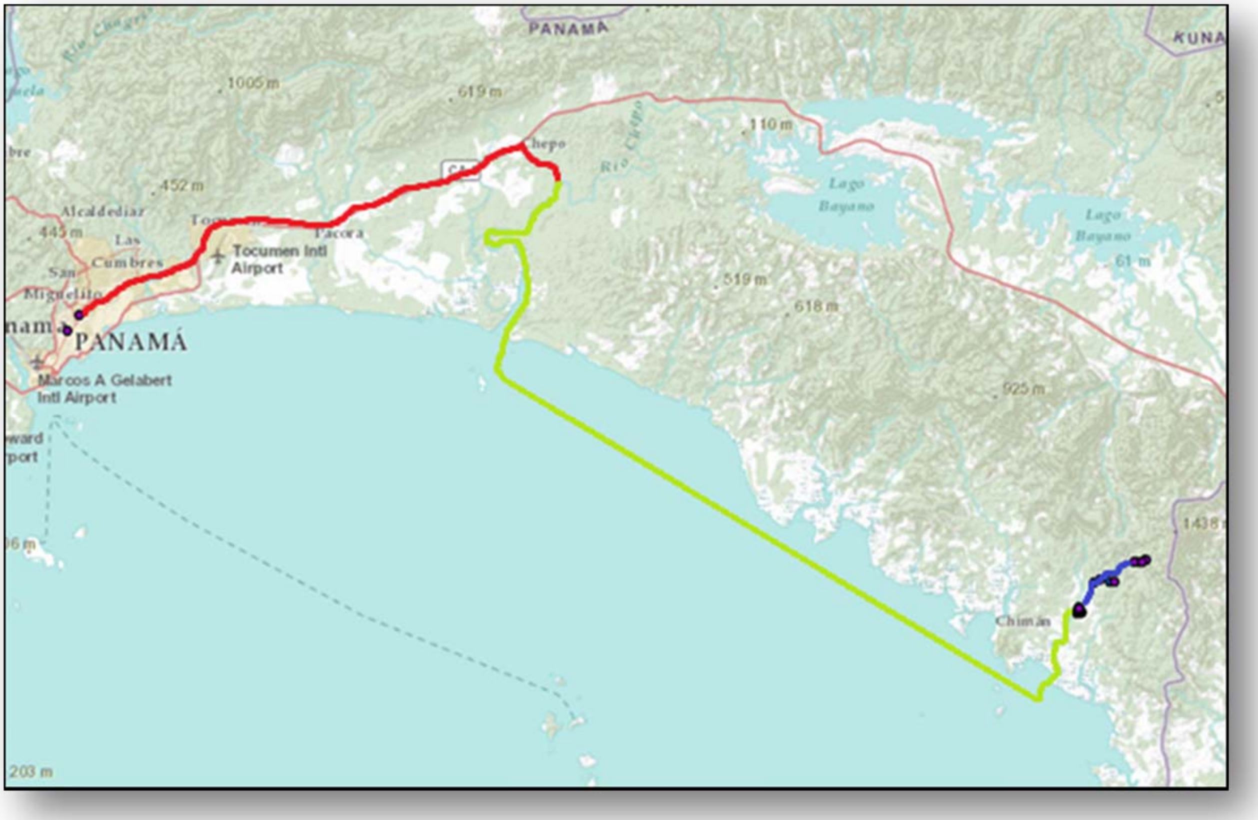


Figure 23: Zapatero Engineering's journey from Panama City, Panama to Majé Chimán

Appendix B – Community Survey Results

To guide Zapatero Engineering's design process, an electrical aspiration assessment was complete to ensure that the system would meet the community's present and future needs. Twenty-two interviews were performed at various locations to provide an adequate survey demographic. A standardized set of interview questions was used with each interviewee to ensure consistency. The trends that emerged from the interview process were commonalities in the kinds of electrical appliances that the community desired as well as why they wanted these items. These interviews provided Zapatero Engineering with not only valuable quantitative data but also significant cultural insights. A summary of these results can be seen below.

Table 8: Community Interview Summary

Interview	Name	Occupation/ Background	Current Energy Use				Future Energy Asperation					Pays nightly fee?	Other Energy Costs per Month				Family Size
			Lights	Television	Iron	Other	Lights	Television	Iron	Washing Machine	Other		Bateries	Candels	Desil	Total	
1	Lecto Mejilla	Farmer, Previously Community Chief and Regional President	-	-	-	-	x	x	-	x	fan	Yes	$ 1.00			**$ 1.00**	5
2	Rafiael	Artist	x	x	-	-	x	x	x	x	-	No	$ 4.00			**$ 4.00**	8
3	Yoni	Artist	x	-	-	-	x	x	x	x		Yes	$ 6.00		$ 16.00	**$ 22.00**	8
4	Eric	Artist	x	x	-	-	x	x	-	x	Refigerator	Yes	$ 2.00		$ 8.00	**$ 10.00**	7
5	Libado	Takes care of Community Electrecian, has a personal solar panel	x	x	x	washing machine	x	x	x	x	Computer	Yes				**$ -**	6
6	Sefrain	Artist	x	-	x	-	x	-	x	-	-	Yes	$ 30.00			**$ 30.00**	3
7	Adelmo	Farmer	x	-	-	-	x	x	-	-	-	Yes	$ 20.00	$ 4.80		**$ 24.80**	4
8	Arafe	Fisherman	x	x	-	-	x	x	x	x	Refigerator, Eletric Tools	Yes	$ 20.00	$ 4.80		**$ 24.80**	5
9	Chiari	Farmer and Artist	x	-	-	-	x	x	-	x	Eletric Tools	Yes	$ 2.00		$ 4.00	**$ 6.00**	6
10	Hyda	Artist	x	-	x	-	x	x	x	x	Refigerator	Yes	$ 4.00			**$ 4.00**	6
11	Habran	Artist	x	x	x	-	x	x	x	x	Refrigerator	Yes	$ 2.00			**$ 2.00**	5
12	Sonneera	Artist	-	-	-	-	x	x	x	x	-	No			$ 4.00	**$ 4.00**	10
13	William	Artist	x	-	-	-	x	x	x	-	-	Yes	$ 8.00			**$ 8.00**	4
14	Mauhee	Artist	x	x	x	-	x	x	x	x	Computer	Yes	$ 6.00			**$ 6.00**	5
15	Carmallina	Artist	x	-	-	-	x	-	x	x	-	No	$ 3.00			**$ 3.00**	8
16	Restrepo	Store Owner has his own personal generator	x	x	-	washing machine, refrigerator	x	x	x	x	Stove	Yes			$ 50.00	**$ 50.00**	2
17	Samuel	Artist	x	-	-	-	x	x	-	-	-	Yes	$ 2.00	$ 36.00		**$ 38.00**	7
18	Aledo	Artist	x	x	-	-	x	x	-	-	Eletric Tools	Yes	$ 6.00			**$ 6.00**	4
19	Luehan	Teacher	-	-	-	-	x	-	x	-	-	No	$ 4.00			**$ 4.00**	5
20	Albemahear	Artist	x	x	-	-	x	x	-	x	Stove	Yes	$ 3.00			**$ 3.00**	4
21	Rolaming	Artist	x	-	x	-	x	x	x	x		Yes	$ 2.00			**$ 2.00**	4
22	Johny	Pastor	x	-	-	-	x	-	-	-	Computer	Yes	$ 15.00	$ 0.60		**$ 15.60**	7

Appendix C – Diversion and Forebay

Diversion Design

The diversion structure can be seen in Figure 24. Up to half the river is to be diverted to acquire the design flow rate of 17.5 cfs through the penstock. A rock gabion will start 10 feet before the water is diverted from the river. The rock gabion is placed well ahead of the diversion to make sure that there is enough water in the system. The actual diversion will consist of a trapezoidal channel, shown in Figure 25. The channel will run downgrade with the terrain and over to the forebay. The channel will connect with the top of the forebay structure.

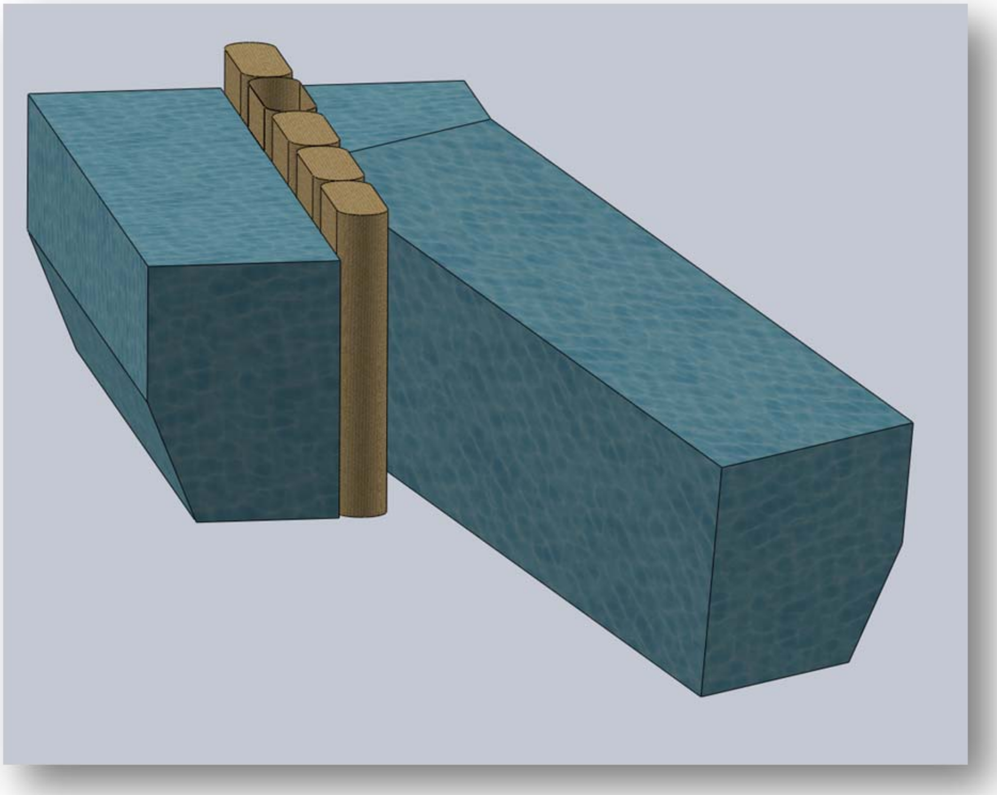


Figure 24: Diversion Structure
Solid Works Model by Christina Matlock

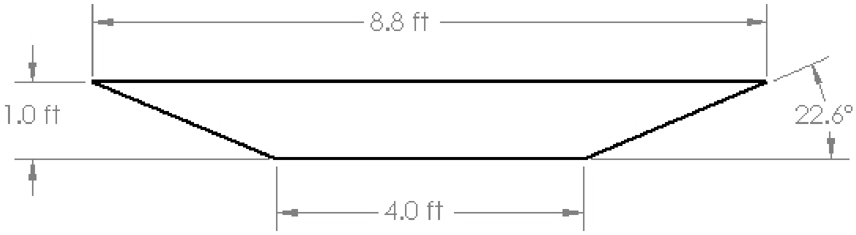


Figure 25: Channel Dimensions

Forebay Design

Source: Arduser, Christian, and Leid Karcheter. *Civil Works for Micro Hydro Power Units*

Assumptions Made

- It was observed that the Zapatero River is rock lined making the sediment concentration very small. For this reason a settling basin was deemed unnecessary and large debris will be captured before the forebay with a screen.
    - The reference cited describes design for both the settling basin and the forebay. The pertinent aspects were taken from the example and adapted to fit the Team's needs.

Volume of Forebay

$$V_{forebay\ tank} = Q_{turbine} * 75 = 17.5\frac{ft^3}{s} * 75 = 1312.5\ ft^3$$

$$H_{forebay\ Tank} = 4 * D_{penstock} + \frac{1}{2} * D_{penstock} = 4 * 1.5ft + .5 * 1.5ft = 6.75\ ft$$

The shape of the forebay can be altered to fit the topography of the area where this tank will lay. The equations prove that a minimum height of 6.75 ft. and a volume of 1312.5 cubic feet are required for the design. For simplicity, it will be assumed that the tank will be a cubic structure with the same length, width and height.

$$V_{forebay\ tank} = L * W * H = (if\ cube\ shaped) 3x = 1312.5 ft^3$$

$$W = 11\ ft, L = 11 ft\ , H = 11\ ft$$

These dimensions represent the inside dimensions of the forebay. The overall the structure will be 12 by 12 by 12 ft. Since the height of the tank is greater than the minimum 6.75 ft., the forebay structure dimensions are deemed appropriate for the system.

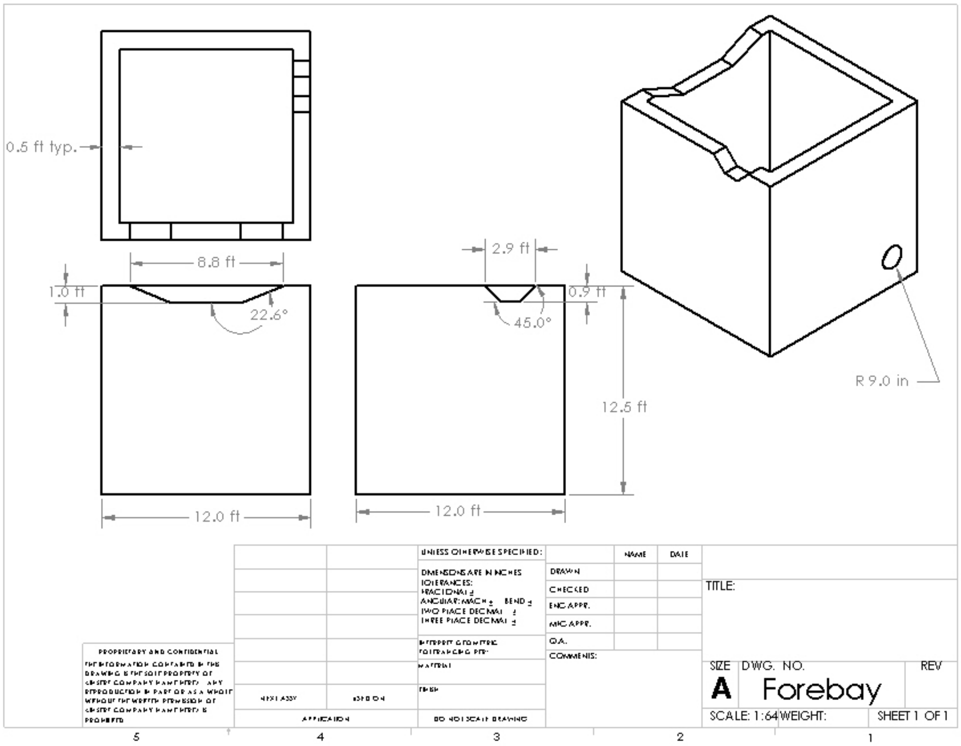


Figure 26: Forebay Dimensioned Drawing

Appendix D –Penstock

Penstock Length Determination

The length of the penstock was calculated by utilizing the GPS coordinates taken while in Panama and by making some simplifying assumptions. Figure 27 below shows the proposed penstock path. The inlet was assumed to be located twenty-five feet upstream from the waterfall. The penstock then diverts sixty feet perpendicular to the river into the jungle. This is because the river and waterfall consist of bedrock. By diverting into the jungle a significant distance, the Team hopes the ground will be comprised of different materials that are far more conducive to implementing an anchoring system for the penstock.

The sloped path from the top of the waterfall down to the generation site is approximately a twelve degree decline. This path was assumed in order to determine the length of penstock. Additional pipe was incorporated into the calculations to account for the simplifying assumptions made. The path then diverts back towards the generation site and drops ten feet, at a 90° angle to the turbine in the housing structure.

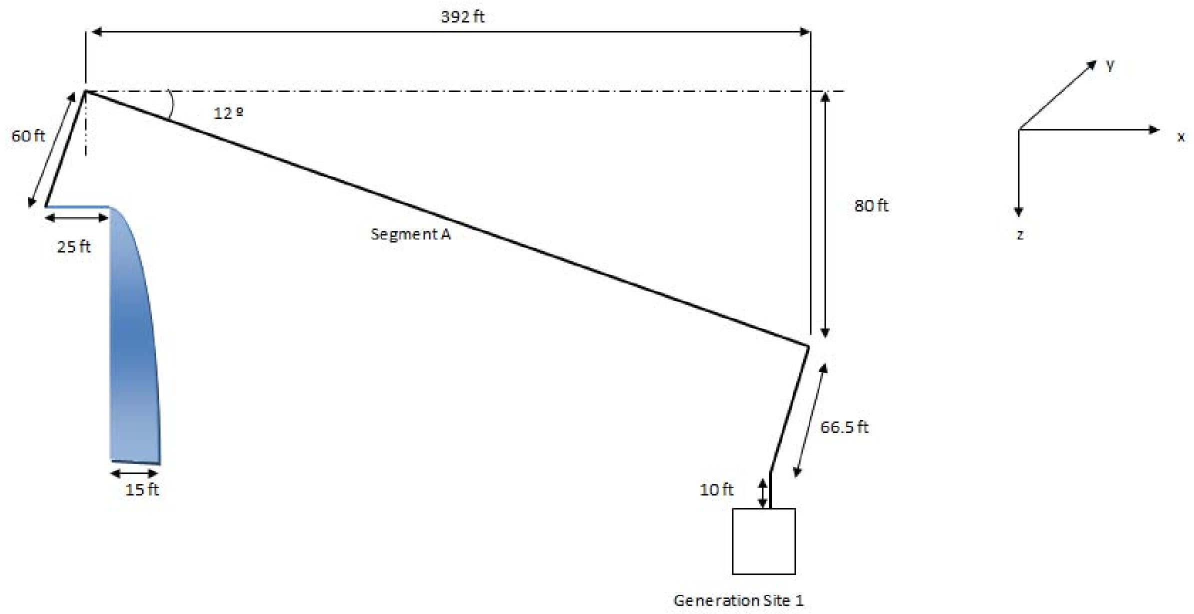


Figure 27: Pipe Length Estimation

From this schematic a pipe length could be determined as summarized below in Table 9. A 20% estimation factor was added to account for the difference between the straight line approximation and the actual pipe path. An additional six feet was added for three bends that could potential occur along Segment A in the above schematic. This total pipe length was used for head loss determination, material needs, and cost estimates.

Table 9: Pipe Length Approximation

Straight Path Approximation (See Figure 3)	538
20 % Estimation Factor	108
6 ft. for each additional bend in Segment A (3 bends)	18
Total Pipe Length (ft.)	**663**

Headloss and Pipe Selection

In order to select the material and size of the pipe, headloss due to friction as well as other minor headlosses were calculated. This investigation gave the Team insight into the total head available to the turbine after accounting for headlosses. This was calculated using the equation below. The headloss was subtracted from the original amount of head available from the Chorro Falls. The headloss included the head lost due to friction, the entrance, four 90° bends, twelve 45° bends, and the exit. The coefficients for the minor losses were found using Wurbs and James (2002) as given in Table 10, while the friction factor for each material was found using the Moody Diagram.

$$H_t = H_0 - \left(f \frac{L}{D} \frac{V_1^2}{2g} + K_{ent} \frac{V_1^2}{2g} + 12 * K_{45°} \frac{V_1^2}{2g} + 4 * K_{90°} \frac{V_1^2}{2g} + K_{exit} \frac{V_1^2}{2g} \right)$$

$$H_t = Head\ available\ to\ Turbine$$

$$H_0 = Original\ Head\ produced\ by\ Chorro\ Falls{:}\ 90ft$$

Table 10: Coefficients for Headloss Equation

Structure	Headloss Coefficients, K
Entrance	0.5
45 Degree Bend	0.4
90 Degree Bend	1.5
Exit	1

The headloss was calculated using four different materials along with three different diameter sizes. The materials used were galvanized iron, galvanized steel, stainless steel, and polyvinyl chloride (PVC) while the three diameters used were 1 foot, 1.5 feet, and 2.0 feet. Table 11 shows the headloss created for the allowable combinations. The general trend is that as the diameter of the pipe increases, the headloss decreases. For all the materials, the 2.0 foot diameter pipe created for the least amount of headloss. The material that allotted for the least amount of headloss and the greatest available head to the turbine is the PVC pipe. While the 2.0 foot diameter PVC pipe has the least amount of headloss, the price difference between the 1.5 foot and 2.0 foot diameter PVC pipe cannot be ignored. Table 12, shows the price difference for 670 feet of PVC pipe needed for the design. Since there is such a large difference between the prices, 1.5 foot diameter pipe was employed for the penstock design.

Table 11: Summary of Headlosses

Pipe Material	Pipe Diameter	Headloss	Remaining Head
Galvanized Iron	1	176.3	-86.3
	1.5	27.8	62.2
	2	7.9	82.1
Galvanized Steel	1	176.3	-86.3
	1.5	27.8	62.2
	2	7.9	82.1
Stainless Steel	1	137.7	-47.7
	1.5	24.0	66.0
	2	7.1	82.9
PVC	1	128.1	-38.1
	1.5	22.8	67.2
	2	6.8	83.2

Table 12: Price Estimate of Penstock Pipe

Price of 670 Feet of Schedule 40 PVC Pipe	
Diameter (ft.)	Price (USD)
1.5	$26,000.00
2	$42,500.00

Thrust Force and Block Analysis

The following is an example calculation for sizing the thrust block for a 90° bend of unburied 18-inch pipe above the midway point of elevation along the penstock.

- Thrust Force Calculation

$$Force\ from\ Velocity$$

$$F_x = \beta * \rho * Q * (V_{2x} - V_{1x})$$

$$F_y = \beta * \rho * Q * (V_{2y} - V_{1y})$$

$$F_v = \sqrt{{F_x}^2 + {F_y}^2}$$

$$Force\ from\ Pressure$$

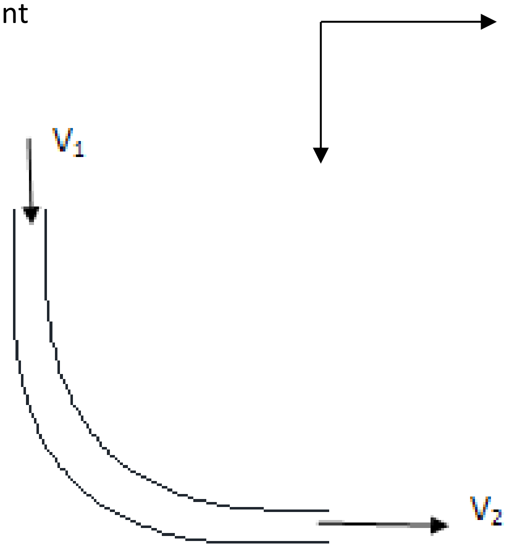
$$P = \rho * h$$

$$F_p = 0.5 * \pi * P * d^2 * \left(\frac{\sin\theta}{2}\right)$$

$$Thrust\ Force$$

$$T = F_v + F_p$$

Sample Calculations: 90° Bend before midway point



$\beta = 1.0$

$\rho = 1000\ kg/m^3$

$h\ @\ End\ Pt = 29\ m$

$h\ @\ Halfway\ Pt = 14.5\ m$

$Q = 0.48\ m^3/s$

$d = 0.4572\ m$

$\theta = 90°$

$V = 2.93\ m/s$

$V_{1y} = 2.93\ m/s$

$V_{2x} = 2.93\ m/s$

$V_{2y} = 0\ m/s$

$F_x = (1.0)(1000)(0.48)(2.93 - 0) = 1406\ N$

$F_y = (1.0)(1000)(0.48)(0 - 2.93) = 1406\ N$

$F_v = \sqrt{1406^2 + 1406^2} = 1988\ N$

$P = (1000) * 14.5 = 144795\ Pa$

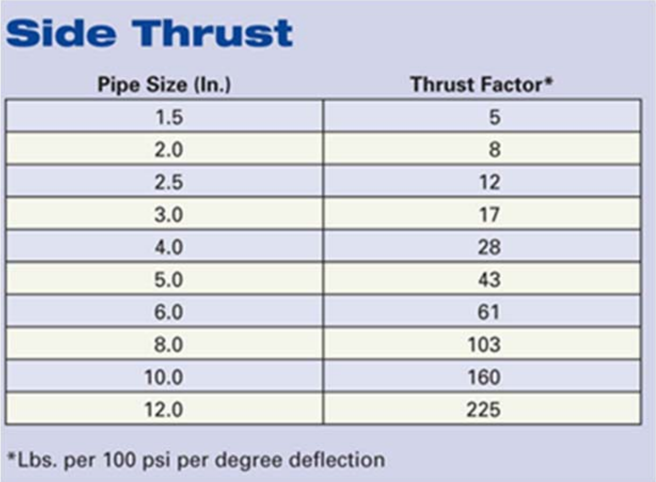
$$F_p = 0.5(\pi)(144795)(0.4572)^2\left(\frac{\sin 90°}{2}\right) = 33617\ (N)$$

$T(Thrust\ Force) = 1988 + 33617 = 35605\ (N)$

- <u>Thrust Block Sizing</u>

*This method is from Home Power, a website for do-it yourself alternative power generation systems. See reference [12] for link, utilizing the thrust force calculated above.

Table 13: Side Thrust Force



Side Thrust

Pipe Size (In.)	Thrust Factor*
1.5	5
2.0	8
2.5	12
3.0	17
4.0	28
5.0	43
6.0	61
8.0	103
10.0	160
12.0	225

*Lbs. per 100 psi per degree deflection

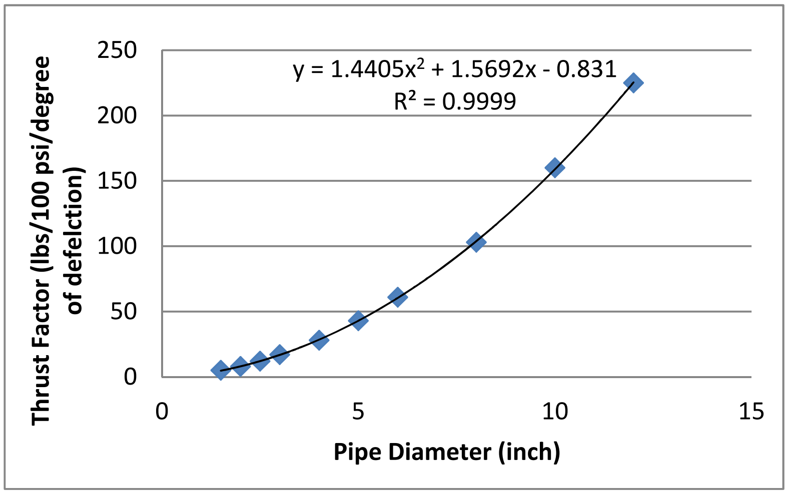


Figure 28: Thrust Factor as a function of pipe diameter [5].

$$Thrust\ Factor = 1.14405 * x^2 + 1.5692 * x - 0.831$$
$$where\ x = pipe\ diameter\ in\ inches$$

$$Thrust\ Factor = 1.14405 * 18^2 + 1.5692 * 18 - 0.831398 = \frac{\mathbf{389\ lb\ force}}{\mathbf{100\ psi * degree}}$$

$$Thrust\ Factor = \frac{398\ lb\ force}{100\ psi * degree} * .\frac{1\ N}{.22481\ lbf} * \frac{1psi}{6894.75\ Pa}$$

$$Thrust\ Factor = \frac{.002568\ N}{Pa}$$

$$Degrees\ of\ Deflection = 90$$

$$Pressure\ Force = \frac{Thrust\ force\ (from\ above)}{Area} = \frac{35605\ N}{\left(\frac{.4572\ m}{2}\right)^2 * \pi} = 216875\ Pa$$

$$Weight\ of\ Force\ Block = Thrust\ Factor * Degrees\ of\ deflection * Pressure\ of\ force$$

$$Weight\ of\ Force\ Block = \frac{.002568\ N}{Pa} * 90 * 216875\ Pa = \ 50130\ N$$

$$50130\ N = \frac{48985 \frac{kg * m}{s^2}}{9.81\ m/s^2} = \ 5110\ kg$$

$$5110\ kg * \frac{1m^3}{2400\ kg} = \mathbf{2.13\ m^3\ is\ how\ large\ the\ force\ block\ should\ be}$$

Table 14: Thrust Block Weight and Size

Location	Magnitude of Bend	Thrust Block Weight (kg)	Thrust Block Volume (m^3)
Above midway point	45 degrees	1281	0.53
	90 degrees	5110	2.13
Below midway point	45 degrees	2318	0.97
	90 degrees	9233	3.85

Appendix E –Generator Site Selection

As seen in Table 16, a decision matrix was created to assist in the generation site selection process. Option 1 is located directly at the base of Chorro Falls. Options 2 and 3 are the surveyed sites located approximately 300 feet downstream from the falls. Option 4 explores the idea of having the water piped to the community and the power generation occurring at the community. Each option was then ranked in relation to the various functions. A weight factor was also implemented into the decision matrix to prioritize the functions based on the design constraints. By multiplying each weight factor by the ranking order, this provided the team with objective information to make an informed selection as to where the turbine and generation site should be located. It can be observed in Table 16 that Option 2 is the leading generation site.

Table 15: Generation Site Options Summary

Name	Location
Option 1	To the Left at the Base of Chorro Falls
Option 2	Surveyed Generation Site 1
Option 3	Surveyed Generation Site 2
Optoin 4	In the Community of Maje

Table 16: Decision Matric of Proposed Generation Sites

Function	Function Importance (1=Least; 7 Most)	Objective	Rating (1=Worst; 4=Best)			
			Option 1	**Option 2**	**Option 3**	**Option 4**
Accessibility	3	Maximize	1	3	2	4
Relation to Flood Plain	6	Maximize	1	3	2	4
Grade of Earth	1	Minimize	1	3	2	4
Area of Site	4	Maximize	2	3	1	4
Available Head	7	Maximize	2	4	3	1
Ground Material	2	N/A	1	3	2	4
Distance from Falls	5	Minimize	4	3	2	1
		Totals	**54**	**91**	**59**	**76**

Appendix F – Housing Design

The housing structure for this project will be located near the base of the waterfall at the specified generation site. This housing unit consists of a thick slab of concrete as its base and the Team assumes the community members will use wooden boards for the walls and corrugated metal sheeting for the roof. This type of housing is similar to the housing found within the community. A model of a possible housing structure can be seen in Housing section in the body of the report. Inside this structure, the placement of the components is very important. Figure 29 shows the layout of the floor of the room. This was based on photos from already made systems that Canyon Hydro has implemented. This structure was designed to hold the components chosen for this design, but could be adapted based on the constraints that the community finds at the generation site as well as their level of skill about housing construction

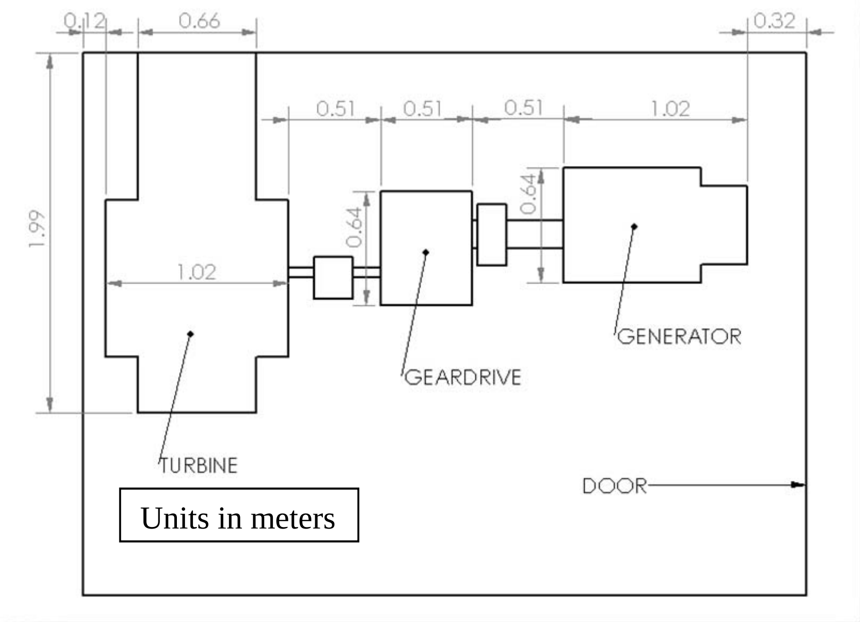


Figure 29: Floor Layout of Housing

Appendix G – Tail Race Design

Tail Race Design

Source: Open Channel Hydraulics – Terry W Sturm [5]

All Figures, Tables, Constants, Equations and method's used from this source

Assumptions Made

Rip rap mean diameter rock size from experience in the field

- d_{50} = 100 mm = 10 cm = .328 ft., very angular

Base of the channel was made as an engineering decision

- b= 4 ft.

Known

- Q, flow = 17.5 ft^3/s

Critical Bed and Wall Shear Stresses

i. Angle of repose of riprap, side slope angle, side slope ratio from mean stone diameter 100mm
    - $\varphi = 41\ degrees$, Figure 4.13 A, Angle of Repose of Riprap
    - $\theta = 23\ degrees$, Figure 4.13 B, Recommended Side Slopes of Trapezoidal Channels
    - $m = 2.4$ Figure 4.13 B, Recommended Side Slopes of Trapezoidal Channel

ii. Maximum Bed Shear Stress

$$\tau_{oc} = 4\, d_{50} = 4 * .33ft = 1.32 \frac{lb}{ft^2}$$

iii. Maximum Sidewall Shear Stress

$$K_r = \frac{\tau_0^w}{\tau_{0c}} = \left(1 - \frac{sin^2(\theta)}{sin^2(\varphi)}\right)^{\frac{1}{2}}$$

$$\tau_0^w = \left(1 - \frac{sin^2(\theta)}{sin^2(\varphi)}\right)^{\frac{1}{2}} * \tau_{0c} = \left(1 - \frac{sin^2(23)}{sin^2(41)}\right)^{\frac{1}{2}} * 1.32 \frac{lb}{ft^2} = 1.06 \frac{lb}{ft^2}$$

Find Normal Depth

i. Manning's *n* based on experimental data on resistance of rock riprap

$$n = .04\, d_{50}^{\frac{1}{6}} = .04 * (.32ft)^{\frac{1}{6}} = .033$$

ii. In order to find the slope of the channel from the housing to the river the critical depth and slope for the given flow was determined. The slope was taken to be less than critical slope because non critical flow was desired.

a. Critical Depth

$$1 = \frac{\alpha * Q^2 * B_c}{g * {A_c}^3} = \frac{\alpha * Q^2 * (b + 2 * my)}{g * \left(y(b + my)\right)^3} = \frac{1 * \left(17.5 \frac{ft}{s}\right)^2 * (4\,ft + 2 * 2.4y)}{\frac{62.4ft}{s^2} * (y(4ft + 2.4y))^3}$$

$y\ (Critical\ depth) = .722$

b. Critical Slope

$$S_c = \frac{n^2 Q^2}{K_n^2 * A_c^2 * R_c^{\frac{4}{3}}} = \frac{n^2 Q^2}{K_n^2 * \left(y(b + my)\right)^2 * \left(\frac{A}{P}\right)^{\frac{4}{3}}}$$

$$= \frac{n^2 Q^2}{K_n^2 * \left(y(b + my)\right)^2 * \left(\frac{\left(y(b + my)\right)}{\left(b + 2y(1 + m^2)\right)^{\frac{1}{2}}}\right)^{\frac{4}{3}}}$$

$$S_c = \frac{(.033)^2 (\frac{17.5ft}{s})^2}{1.49^2 * \left(.722(4 + 2.4 * .722)\right)^2 * \left(\frac{\left(.722(4 + 2.4 * .722)\right)}{\left(4 + 2 * .722(1 + 2.4^2)\right)^{\frac{1}{2}}}\right)^{\frac{4}{3}}}$$

$S_c = .01669\ ft/ft$ --> **Assumed slope of .01**

iii. Normal Depth

$$Q = \frac{K_n}{n} * A * R^{\frac{2}{3}} * S^{\frac{1}{2}} = \frac{K_n}{n} * \left(y(b + my)\right) * \left(\frac{\left(y(b + my)\right)}{\left(b + 2y(1 + m^2)\right)^{\frac{1}{2}}}\right)^{\frac{2}{3}} * S^{\frac{1}{2}}$$

$$17.5 \frac{ft}{s} = \frac{1.49}{.033} * \left(y(4 + 2.4y)\right) * \left(\frac{\left(y(4 + 2.4y)\right)}{\left(4 + 2y(1 + 2.4^2)\right)^{\frac{1}{2}}}\right)^{\frac{2}{3}} * .01^{\frac{1}{2}}$$

$y = .872776 = normal\ depth$

Compute Maximum Shear Stresses

To compare to maximum values to critical shear stresses found earlier

i. Maximum Bed Shear Stress

$$\tau_{oc}\,max = 1.5\gamma RS = 1.5 * 62.4\frac{lb}{ft^3} * \left(\frac{(.873(4 + 2.4 * .873))}{(4 + 2 * .873(1 + 2.4^2))^{\frac{1}{2}}}\right) * .01$$

$$\tau_{oc}\ \max = .582\frac{lb}{ft^2} < \tau_{oc} = 1.312\frac{lb}{ft^3}\ (calculated\ above)$$

Bed can withstand the shear stress of water passing over it

ii. Maximum Sidewall Shear Stress

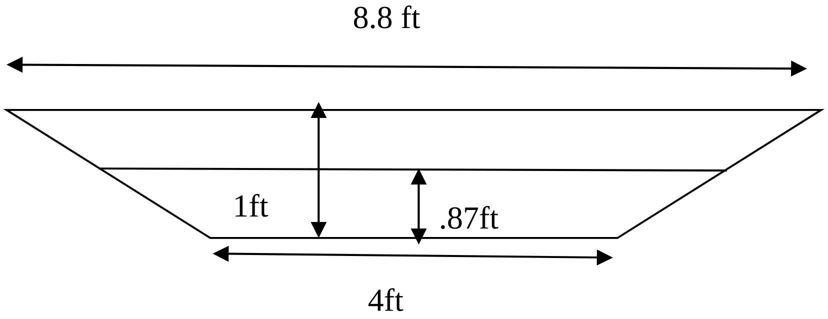
$$\tau_{oc}\,max = 1.2\gamma RS = 1.2 * 62.4\frac{lb}{ft^3} * \left(\frac{(.873(4 + 2.4 * .873))}{(4 + 2 * .873(1 + 2.4^2))^{\frac{1}{2}}}\right) * .01$$

$$\tau_{oc}\ \max = .466\frac{lb}{ft^2} < \tau_{oc} = 1.06\frac{lb}{ft^3}\ (calculated\ above)$$

Side walls can withstand the shear stress

Final Sizing

Note: Diagram is not to scale



Flow through Channel

$$Q = V * A$$

$$V = \frac{Q}{A} = \frac{\frac{17.5ft^3}{s}}{y(4 + 2.4y)} = \frac{\frac{17.5ft^3}{s}}{1\,ft(4ft + 2.4 * 1ft\,)} = 2.36\frac{ft}{s}$$

This is an apropirate velocity for a channel of this nature

Appendix H – Turbine and Power Calculations

The turbine selected is a cross flow turbine which is classified as an impulse turbine. This kind of device utilizes a wheel with angled fins that allow the water to freely flow through, resulting in the spinning of the turbine. The nozzle for the cross flow turbine is rectangular in shape. The below equations were found online in spreadsheet form [13]; the developer of this spreadsheet found optimum dimensions for a turbine of this kind from his own research and personal experience building a micro-hydroelectric system for his home. The team verified his processes by consulting an additional source developed by the Department of Trade and Industry, of the United Kingdom [14]. The Team inputted the measurements made from Churro Falls and used some of the numbers from the spreadsheet to find the approximate dimensions of a suitable turbine on the Zapatero River.

1.0 Power Calculations

(Angles in radians)

1.1 Total Head determination

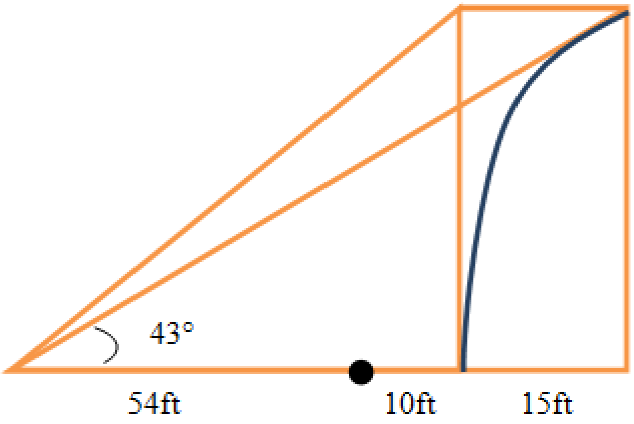


Figure 30: Waterfall height determination

Figure 30 shows what the Team drew for calculating the height of the waterfall. The dark line is a representation of the waterfall and the orange line with the angle is the view with the Abney level. Using trigonometry the actual height of the water fall was calculated. The black dot represents a teammate who swam out as close to the base with a rope to measure the approximate distance to the base of the falls. Using this information, an additional 15 feet was added to the horizontal distance. The equation below shows part of the calculations. The four represents an estimated distance off the ground from where the Abney level was used. Using all of this information, an approximate height of the waterfall was calculated to be about 78.5 feet high. 11.5 feet was added to the total head to account for the elevation difference between the generation site and the base of the waterfall, which sums to 90 feet (28.8 m) of head.

$$\tan(43.5) \times 78.5 + 4 = 78.5\ \text{ft} \longrightarrow 90\text{ft}\ \ (28.77\text{m})$$

This is the total head availble. As seen in the Appedix D-Penstock there are headlosses within the pipe due to friction and direction changes. The resulting head available to the turbine accounting for all headlosses is 67 ft. (20.42 m).

1.2 Flow Rate Determination

Flow rates were determined using the float method-measuring the time for an empty plastic bottle to float a certain distance. The test spanned 12 feet and the time for an empty plastic bottle to travel that distance was recorded. Two cross sections were measured along this 12 foot span. The averages were calculated of the three times and an average cross section was created as seen in Figure 31. Using these flowrate could be determined.

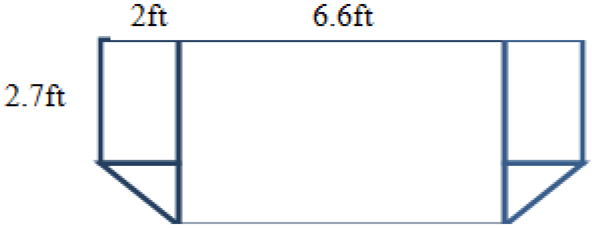


Figure 31: Average River Cross Section

Time 1st spot: 7.18, 6.35, 8.16 = 7.23s

Time 2nd spot: 18.03, 25.15, 29.50 = 24.23s

Average velocity = 0.76 ft. /s

Multiplied with the average velocity, it yielded the flow rate as follows

Cross sectional area = 42.38 ft^2

Cubic flow rate = 32.33 $\text{ft}^3/\text{s} \longrightarrow 0.916\ \text{m}^3/\text{s}$

Readings were taken two days previous at the first waterfall that was visited, Salto. The water was flowing in a straight channel shape, so the cross sectional area was easier to calculate. The same method as described above was employed with the only exception being that a traveling distance of 16 feet was used. The flowrate calculations of the river at Salto Falls are displayed below.

Time: 4.81, 4.97, 4.77 = 4.86s

Average velocity = 3.3 ft. /s

Cross sectional area = 25.6 ft^2

Cubic flow rate = 84.45 $ft^3/s \longrightarrow 2.39\ m^3/$

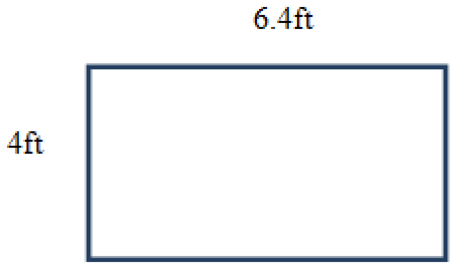


Figure 32: Second River Cross Section

1.3 Power Determination

To find the power available from the waterfall, a power output equation was employed. The efficiency factor of 0.8 accounts for power lost due to the conversion of mechanical energy to electrical energy and is specific to the cross flow turbine. This power equation is as follows:

$$\propto QH \times 0.8 = \mathrm{P}$$

α = specific weight of water (9.8 kN/m^3)

Q = cubic flow rate

H = height

0.8 = efficiency

It is good practice, for environmental reasons, to only divert only half the river's flow. For a conservative estimate of power the flow of the river is assumed to be 1 m^3/s and therefore a flow rate of 0.5 m^3/s was used for power calculations. The power generated by the turbine is this estimated as follows:

9.8 kN/m^3 (.5m^3/s) (20.42 m) (0.8) = 233.02 kW /2 = 80.15 kW

1.4 Turbine Specifications

Dimensions (Provided by Turbine Manufacture)
Outer Diameter (D_1) = 32 in
Ratio (inner/outer) = 0.6
Inner diameter (D_2) = 19.2 in
Angle of attack (α) = 22°
Blade exit angle (β_2) = 55°
Nozzle entry arc (ϒ) = 90°
Number of blades (nB) = 30
Speed ratio = 0.7

Calculations [10]

- **Nozzle throat width**
  $(\sin\frac{\alpha\pi}{180} \times D_1 \times \gamma \times \frac{\pi}{180}) \div 2$ =9.41 in
- **Blade inlet angle (β_1)**
  $\frac{180}{\pi} \times \tan^{-1}(2 \times \tan\frac{\alpha\pi}{180})$ = 38.94°
- **Radius of blade curvature**
  $\frac{\frac{D_1}{4}\times(1-ratio^2)}{\cos\frac{\beta_1\pi}{180} - ratio\times\cos\frac{\beta_2\pi}{180}}$ = 11.81 in
- **Blade central angle**
  $\frac{180}{\pi} \times 2 \times \tan^{-1}\frac{\cos\frac{\beta_1\pi}{180} - ratio\times\cos\frac{\beta_2\pi}{180}}{\sin\frac{\beta_1\pi}{180} + ratio\times\sin\frac{\beta_2\pi}{180}}$ = 42.33°
- **Speed of water jet**
  $60 \times \sqrt{2 \times 32.2 \times Net\ head}$ = 3942.97 ft/min
- **Turbine runaway speed**
  $\frac{water\ jet\ speed}{\pi\times D_1 \div 12}$ = 470.66 RPM

- **Peak efficiency speed**
  speed ratio x runaway speed = 329.46 RPM

- **Gear ratio to 1800 RPM**
  1800/peak speed = 5.46

- **Nozzle width**

$$\frac{1728\times 60\times Q}{peak\ speed\times\pi\times(\frac{D_1}{2}^2-\frac{D_2}{2}^2)} = 10.8\text{ in}$$

- **Runner width (B)**
  1.5 X nozzle width = 16.2 in

- **Aspect ratio** (.33 - .50 preferred)
  $B/D_1 = 0.51$

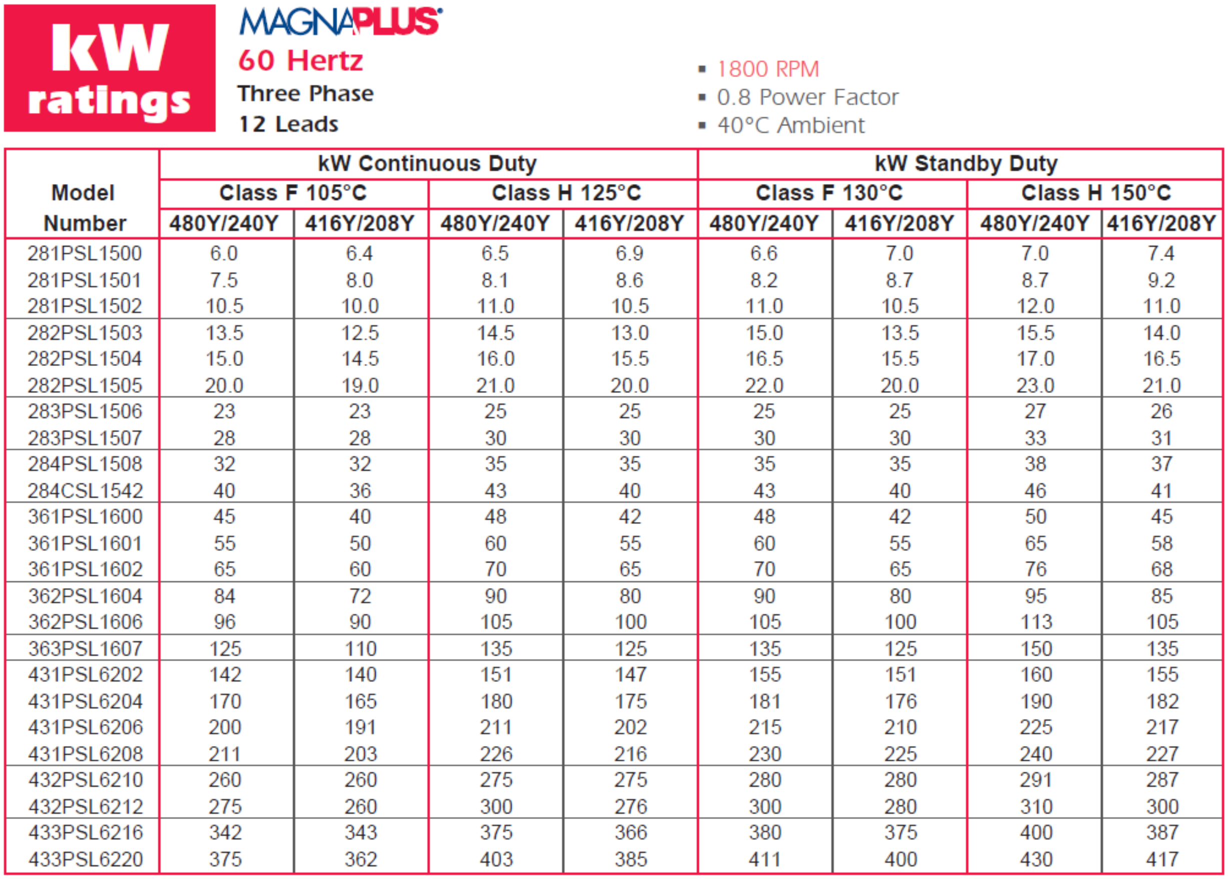
- **Linear speed**
  speed ratio X water jet speed = 2760.08 ft. /min

- **Belt tension**
  44253.73 X power / linear speed = 1285.1 lbs.

Appendix I – Generator

The Marathon MagnaPlus 362PSL1604 generator is the model displayed below in Table 17. This table shows in the Class F section at “kW Continuous Duty”, that 84 kW can be generated. This output meets our power available within the system. Figure 34 shows specific components of the generator. This diagram is useful if a replacement component is required or system maintenance needs to be completed.

Table 17: Generator Specifications [15]



kW ratings

MAGNAPLUS

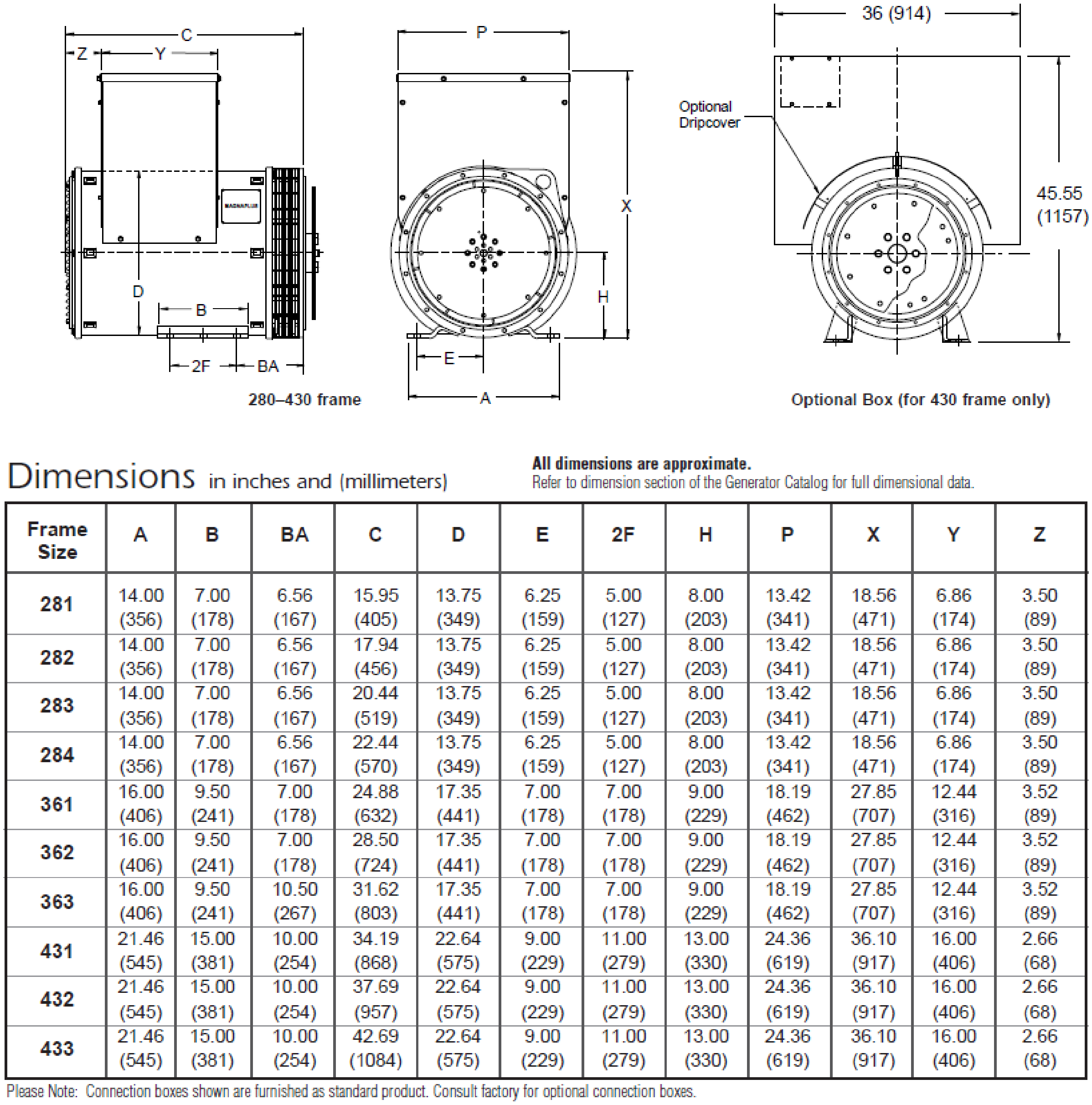
60 Hertz

Three Phase

12 Leads

- 1800 RPM
- 0.8 Power Factor
- 40°C Ambient

Model Number	kW Continuous Duty				kW Standby Duty			
	Class F 105°C		Class H 125°C		Class F 130°C		Class H 150°C	
	480Y/240Y	416Y/208Y	480Y/240Y	416Y/208Y	480Y/240Y	416Y/208Y	480Y/240Y	416Y/208Y
281PSL1500	6.0	6.4	6.5	6.9	6.6	7.0	7.0	7.4
281PSL1501	7.5	8.0	8.1	8.6	8.2	8.7	8.7	9.2
281PSL1502	10.5	10.0	11.0	10.5	11.0	10.5	12.0	11.0
282PSL1503	13.5	12.5	14.5	13.0	15.0	13.5	15.5	14.0
282PSL1504	15.0	14.5	16.0	15.5	16.5	15.5	17.0	16.5
282PSL1505	20.0	19.0	21.0	20.0	22.0	20.0	23.0	21.0
283PSL1506	23	23	25	25	25	25	27	26
283PSL1507	28	28	30	30	30	30	33	31
284PSL1508	32	32	35	35	35	35	38	37
284CSL1542	40	36	43	40	43	40	46	41
361PSL1600	45	40	48	42	48	42	50	45
361PSL1601	55	50	60	55	60	55	65	58
361PSL1602	65	60	70	65	70	65	76	68
362PSL1604	84	72	90	80	90	80	95	85
362PSL1606	96	90	105	100	105	100	113	105
363PSL1607	125	110	135	125	135	125	150	135
431PSL6202	142	140	151	147	155	151	160	155
431PSL6204	170	165	180	175	181	176	190	182
431PSL6206	200	191	211	202	215	210	225	217
431PSL6208	211	203	226	216	230	225	240	227
432PSL6210	260	260	275	275	280	280	291	287
432PSL6212	275	260	300	276	300	280	310	300
433PSL6216	342	343	375	366	380	375	400	387
433PSL6220	375	362	403	385	411	400	430	417



Dimensions in inches and (millimeters)

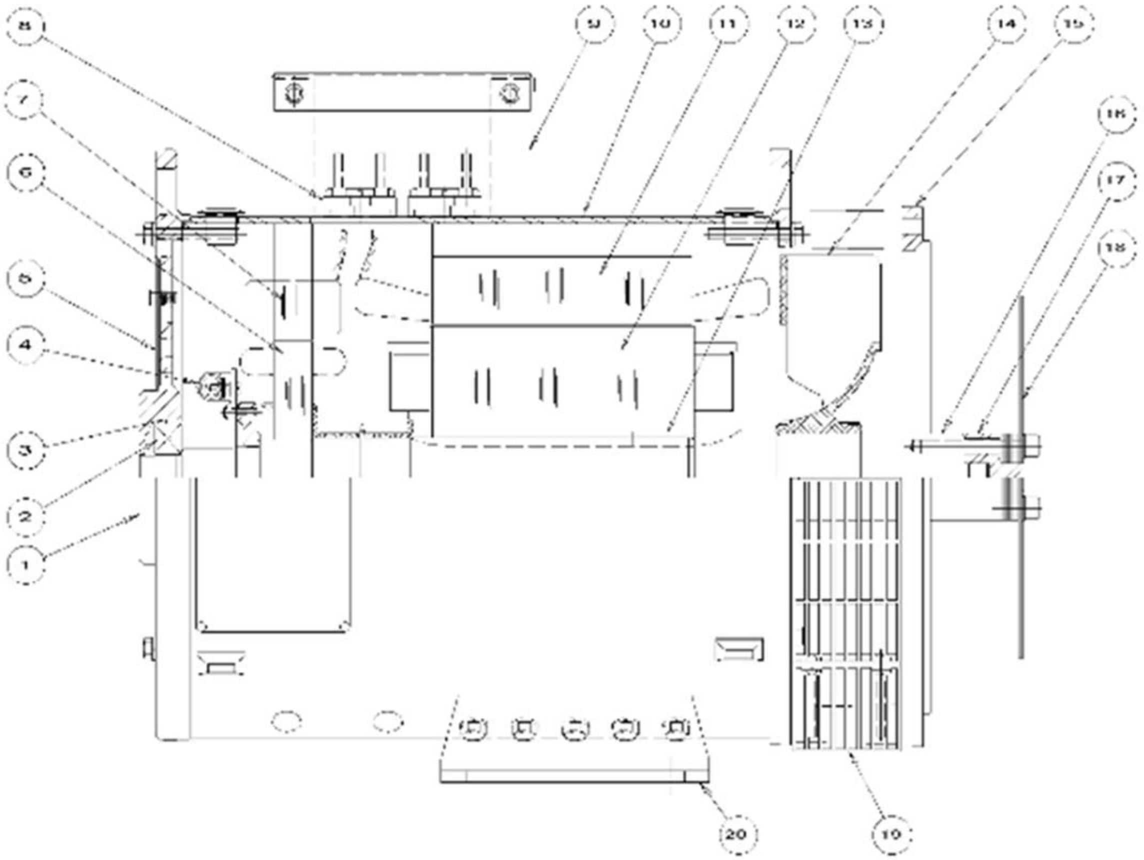
All dimensions are approximate.
Refer to dimension section of the Generator Catalog for full dimensional data.

Frame Size	A	B	BA	C	D	E	2F	H	P	X	Y	Z
281	14.00 (356)	7.00 (178)	6.56 (167)	15.95 (405)	13.75 (349)	6.25 (159)	5.00 (127)	8.00 (203)	13.42 (341)	18.56 (471)	6.86 (174)	3.50 (89)
282	14.00 (356)	7.00 (178)	6.56 (167)	17.94 (456)	13.75 (349)	6.25 (159)	5.00 (127)	8.00 (203)	13.42 (341)	18.56 (471)	6.86 (174)	3.50 (89)
283	14.00 (356)	7.00 (178)	6.56 (167)	20.44 (519)	13.75 (349)	6.25 (159)	5.00 (127)	8.00 (203)	13.42 (341)	18.56 (471)	6.86 (174)	3.50 (89)
284	14.00 (356)	7.00 (178)	6.56 (167)	22.44 (570)	13.75 (349)	6.25 (159)	5.00 (127)	8.00 (203)	13.42 (341)	18.56 (471)	6.86 (174)	3.50 (89)
361	16.00 (406)	9.50 (241)	7.00 (178)	24.88 (632)	17.35 (441)	7.00 (178)	7.00 (178)	9.00 (229)	18.19 (462)	27.85 (707)	12.44 (316)	3.52 (89)
362	16.00 (406)	9.50 (241)	7.00 (178)	28.50 (724)	17.35 (441)	7.00 (178)	7.00 (178)	9.00 (229)	18.19 (462)	27.85 (707)	12.44 (316)	3.52 (89)
363	16.00 (406)	9.50 (241)	10.50 (267)	31.62 (803)	17.35 (441)	7.00 (178)	7.00 (178)	9.00 (229)	18.19 (462)	27.85 (707)	12.44 (316)	3.52 (89)
431	21.46 (545)	15.00 (381)	10.00 (254)	34.19 (868)	22.64 (575)	9.00 (229)	11.00 (279)	13.00 (330)	24.36 (619)	36.10 (917)	16.00 (406)	2.66 (68)
432	21.46 (545)	15.00 (381)	10.00 (254)	37.69 (957)	22.64 (575)	9.00 (229)	11.00 (279)	13.00 (330)	24.36 (619)	36.10 (917)	16.00 (406)	2.66 (68)
433	21.46 (545)	15.00 (381)	10.00 (254)	42.69 (1084)	22.64 (575)	9.00 (229)	11.00 (279)	13.00 (330)	24.36 (619)	36.10 (917)	16.00 (406)	2.66 (68)

Please Note: Connection boxes shown are furnished as standard product. Consult factory for optional connection boxes.

Figure 33: Specific Components of Generator [16]

PARTS LIST – SINGLE BEARING
Typical Generator Cross Section



Reference Number	Part Name	Reference Number	Part Name
1	End Bracket (under end cover 360 & 430 frames)	11	Main Stator
2	Bearing	12	Main Rotor
3	O-ring (280 frame only)	13	Rotor Integral Keyway
4	Rectifier Assembly	14	Fan
5	Air Intake Screen (280 frame only)	15	Mounting Adapter (SAE)
6	Exciter Rotor	16	Shaft
7	Exciter Stator	17	Drive Hub
8	Link Board (terminal block)	18	Drive Disk (SAE)
9	Conduit Box	19	Exhaust Screen (drip cover not shown)
10	Generator Frame	20	Mounting Base

Note: Illustration above is a 280 frame MagnaPlus. Other Frame sizes are typical. Optional PMG not shown. The generator model and serial numbers are required when ordering parts.

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Figure 34: More detailed view of Generator components [16]

Appendix J – Transmission

Transmission Calculations

Cable Size 2/0 AWG
Aluminum Material
With 4160V Transformer

$$Power\ (W) = \ Voltage(V) * Current(A)$$

86420 Watts available in the system after the efficiency losses:

$$86420W = \ 4160V * Current(A)$$

Current = 20.8 Amps

$$Resistance(\Omega) = \frac{Resivity(\Omega - m) * Length(m)}{Area(m^2)}$$

Assumptions:

- Area of 2/0 AWG transmission cable is $6.7(10^{-5})$ meters^2,
- Aluminum has a resistivity constant of $2.65(10^{-8})$ Ohm-meters,
- The cable is 12,000 meters long:

$$Resistance(\Omega) = \frac{2.65(10^{-8})(\Omega - m) * 12{,}000(m)}{6.7(10^{-5})(m^2)}$$

Resistance = 4.75 Ohms

$$Power_{Loss}(W) = Current\ (A)^2 * Resistance(\Omega) = \frac{Voltage\ Drop(V)^2}{Resistance(\Omega)}$$

$$Power_{Loss}(W) = 19.3(A)^2 * 4.75(\Omega)$$

Power Loss = 1.751 kW

$$Power_{Available}(W) = Power_{Before}(W) - Power_{Loss}(W)$$

$$Power_{Available}(W) = 80150(W) - 1751(W)$$

Available Power = 78.4 kW

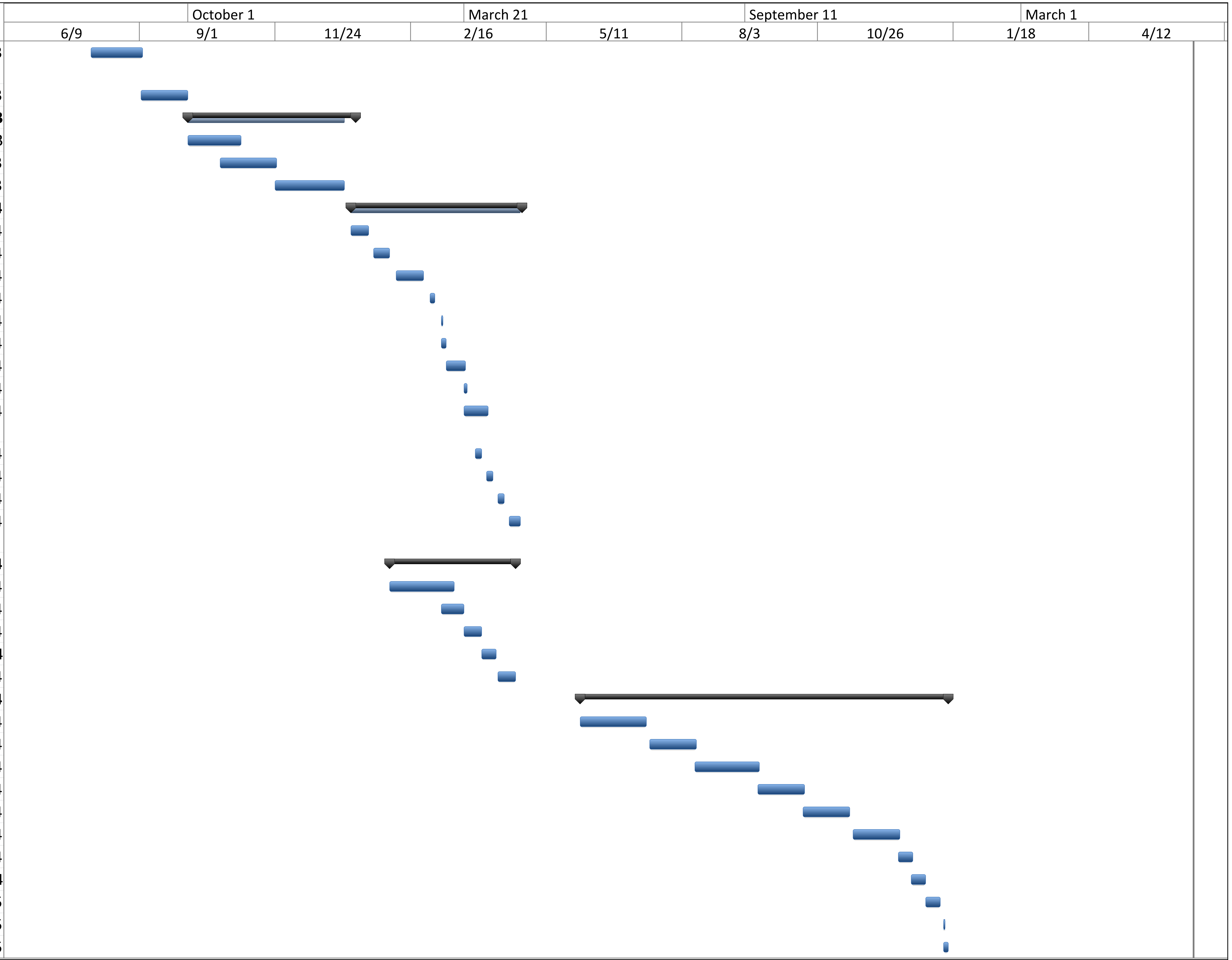
Table 18: Transmission Line Losses

				Aluminum Transmission Cable					Aluminum Transmission Cable			
P=IxV				Power Loss Due To Resistivity (W)					Available Power At Community (kW)			
Power (kW)	Volts (V)	Current (Amps)		Cable Size 4/0	Cable Size 3/0	Cable Size 2/0	Cable Size 1/0		Cable Size 4/0	Cable Size 3/0	Cable Size 2/0	Cable Size 1/0
80.15	240	334.0		331457.5	417246.6	526201.2	662915.1		-251.31	-337.10	-446.05	-582.77
80.15	480	167.0		82864.4	104311.6	131550.3	165728.8		-2.71	-24.16	-51.40	-85.58
80.15	600	133.6		53033.2	66759.4	84192.2	106066.4		27.12	13.39	-4.04	-25.92
80.15	1000	80.2		19092.0	24033.4	30309.2	38183.9		61.06	56.12	49.84	41.97
80.15	2500	32.1		3054.7	3845.3	4849.5	6109.4		77.10	76.30	75.30	74.04
80.15	4160	19.3		1103.2	1388.8	1751.4	2206.4		79.05	78.76	78.40	77.94
80.15	5000	16.0		763.7	961.3	1212.4	1527.4		79.39	79.19	78.94	78.62
80.15	10000	8.0		190.9	240.3	303.1	381.8		79.96	79.91	79.85	79.77
80.15	20000	4.0		47.7	60.1	75.8	95.5		80.10	80.09	80.07	80.05

Appendix K– Construction Manual and Schedule

Construction Schedule

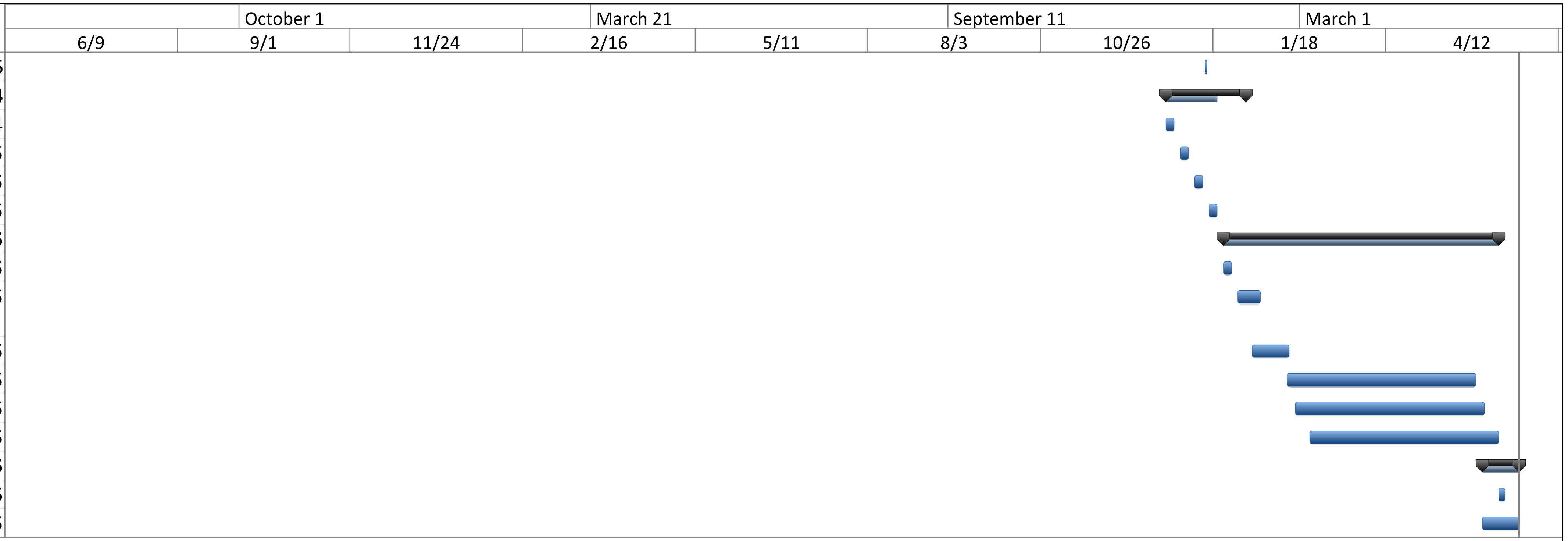
ID	ℹ	Task Name	Duration	Start
1	▦	Determine Route of Road and Penstock	22 days	Fri 8/2/13
2	▦	Order all Materials Needed	21 days	Mon 9/2/13
3		**Path**	**78 days**	**Tue 10/1/13**
4	▦	Clear Brush	25 days	Tue 10/1/13
5	▦	Tree Removal	27 days	Mon 10/21/13
6	▦	Gravel	32 days	Sun 11/24/13
7		**Housing**	**76 days**	**Fri 1/10/14**
8	▦	Clear Brush	7 days	Fri 1/10/14
9	▦	Clear Trees	6 days	Fri 1/24/14
10	▦	Haul Materials	11 days	Fri 2/7/14
11	▦	Slab Form	1 day	Fri 2/28/14
12	▦	Rebar	1 day	Fri 3/7/14
13	▦	Pour Slab	1 day	Fri 3/7/14
14	▦	Cure Concrete	10 days	Mon 3/10/14
15	▦	Remove Form	1 day	Fri 3/21/14
16	▦	Construct Load Bearing Columns and Side Walls	11 days	Fri 3/21/14
17	▦	Erect Columns	2 days	Fri 3/28/14
18	▦	Erect Side Walls	2 days	Fri 4/4/14
19	▦	Assemble Roof	2 days	Fri 4/11/14
20	▦	Clear Area of remaining materials	5 days	Fri 4/18/14
21		**Materials Haul**	**56 days**	**Mon 2/3/14**
22	▦	Piping	30 days	Mon 2/3/14
23	▦	Thrust Block Concrete	10 days	Fri 3/7/14
24	▦	Rebar	7 days	Fri 3/21/14
25	▦	Metal Mesh	7 days	Tue 4/1/14
26	▦	Misc.	7 days	Fri 4/11/14
27		**Inlet / Penstock / Forebay**	**164 days**	**Sun 6/1/14**
28	▦	Clear Path	31 days	Sun 6/1/14
29	▦	Lay Piping Out	21 days	Mon 7/14/14
30	▦	Construct River Diversion	30 days	Mon 8/11/14
31	▦	Dig Area of Forebay	21 days	Fri 9/19/14
32	▦	Construct Channel to Forebay	21 days	Fri 10/17/14
33	▦	Construct Forebay	21 days	Mon 11/17/14
34	▦	Connect Piping Together	7 days	Mon 12/15/14
35	▦	Anchor Piping to Ground	7 days	Tue 12/23/14
36	▦	Construct Thrust Blocks	7 days	Thu 1/1/15
37	▦	Test System	1 day	Mon 1/12/15
38	▦	Let Penstock Pipe Dry Out	3 days	Mon 1/12/15



Project: Zapatero Construction.m
Date: Wed 12/12/12

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	]		

ID	ℹ	Task Name	Duration	Start
39	▦	Cap Penstock Pipe	1 day	Wed 1/14/15
40		**Generator / Turbine**	**27 days**	**Fri 12/26/14**
41	▦	Haul Turbine and Generator	2 days	Fri 12/26/14
42	▦	Haul Misc Materials	2 days	Fri 1/2/15
43	▦	Connect Turbine to Penstock	2 days	Fri 1/9/15
44	▦	Connect Generator to Turbine	2 days	Fri 1/16/15
45		**Power Lines**	**96 days**	**Fri 1/23/15**
46	▦	Locate Points of Crossings	2 days	Fri 1/23/15
47	▦	Haul Materails for Crossing to Crossings	7 days	Fri 1/30/15
48	▦	Construct Line Crossing	12 days	Fri 2/6/15
49	▦	Dig Half Kilometer Segment	66 days	Mon 2/23/15
50	▦	Lay Line	66 days	Fri 2/27/15
51	▦	Cover Line	66 days	Fri 3/6/15
52		**Clean Up**	**13 days**	**Fri 5/29/15**
53	▦	Test System	2 days	Sat 6/6/15
54	▦	Remove all equipment	13 days	Fri 5/29/15



Project: Zapatero Construction.m
Date: Wed 12/12/12

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	]		

Construction Manual

Prior to Construction

Prior to the actual construction of the micro-hydroelectric system, the construction workers need to make preliminary estimates to ensure correct planning has been done for the project and the correct amount of material is ordered. A path to the generation site should be scouted, noting the number of river crossings and large obstacles. For each river crossing it should be determined if large pieces of equipment can be transported across by foot, and if not, a plan needs to be made to overcome the obstacle. The construction crew also needs to accurately determine the penstock path for material ordering. The schedule shows one month for scouting and material ordering. Materials ordered should be transported to the community by truck during the dry seasons throughout the two year construction period and stored at the community. When possible, material should be hauled up to the site and stored in the generator housing.

Path

The jungle terrain outside of Majé Chimán makes the transportation of large pipes, construction materials, a generator, and a turbine difficult. Therefore a path will need to be initially constructed that traverses the seven miles (11 km) in order to complete the project. This path needs to be approximately two and a half meters wide. The path should be built with a slight down grade from the centerline leading water to the sides of the path. Ditches approximately one meter by one meter in a triangular shape should be built on both sides of the path for excess water runoff. A small pile of gravel or rock should be placed in the ditches every half kilometer to manage the runoff. The path should follow the most direct route but the amount of trees cut down should be minimized by directing the path around large trees when possible. The schedule allows for three months of construction for the path.

Housing

The housing for the generator needs to be the first aspect built after the construction of the path. This housing will be used for storage of material and for human shelter. Traveling to the waterfall and back takes an entire day so it would be ideal if construction members could stay in the generator housing for a couple of days at a time to maximize their potential work time. The housing construction is scheduled for the dry season. If construction of the path is completed ahead of schedule then clearing of the generation site can begin. The housing will be 12 x 9 feet. The slab form should be built on top of a two foot exit pipe, placed in a trench below the level of the concrete floor. A pipe elbow needs to be included in the slab form at the point of water exit of the turbine. The concrete should be poured and leveled in such a way around the pipe to create a grade that encourages the water drainage around the pipe.

The suggested housing design is a concrete slab floor, wooden support columns, wooden sides, and plastic corrugated roof. The Team believes the community is proficient at house building and does not plan to provide more detailed construction specifics.

Penstock

Penstock construction is scheduled to take six months. The path of the penstock, determined earlier, will need to be cleared out. The pipe will be laid and connected in place. Then at the 45° and 90° bends, concrete thrust blocks need to be constructed. The sizing requirements for these thrust blocks are included in Appendix D-Penstock. Thrust block forms should be constructed around the corners and rock placed in the forms so that the thrust block encases the corner. After the thrust blocks have been completed the pipe will need to be anchored in place. The piping will have extra support along the path held in by rebar bent into U shapes and inverted over the pipe into bore holes, 18 inches deep, on either side. These holes will then need to be filled with concrete. In the portions in which the pipe traverses rock, bore holes will need to be made into the rock with a jack hammer. A butterfly valve should be installed on the penstock directly before the pipe enters the housing unit. This valve can be found in the cost estimate and facilitates a slow stop of the water flow in the pipe to reduce the risk of water hammer and allows for maintenance on the turbine and generator.

Inlet and Forebay

The penstock needs to be constructed before the inlet but consideration of where the ideal forebay structure location should be made before penstock path is finalized. The river should be diverted in a spot where the water can flow into the channel then enter the forebay at the top. The forebay structure should be tucked into the rock wall to allow the channel from the river to flow into the top of the forebay. The penstock piping would start at the bottom of the forebay structure. The river diversion will consists of a rock gabion separating the river into two halves. One half of the river will continue downstream like normal but the other half will be diverted through a man-made channel into the forebay. The rock gabion will be metal meshing filled with rocks supported by rebar at the corners. The channel leading to the forebay is illustrated later on. The forebay structure is a made out of poured concrete with rebar supports. The top of the forebay will be protected by corrugated plastic sheeting over the top. This cover will be elevated just enough to allow water to overflow from the forebay in case of flooding. The cover will be elevated using cut pieces of rebar.

Generator and Turbine Hook up

The generator and turbine hook up will need to be completed by a professional skilled labor. It should also be noted that a professional engineer will need to be hired to oversee the project and is included in our cost estimate. It was assumed that the professional does not need to work every day during construction but act more as a consultant with a few construction visits.

Transmission Lines

The installation of the transmission lines will be one of the final steps of the overall construction process. The line will run the seven miles (11 km) from the generation site to the community of Majé. The transmission cable has adequate insulation that will allow the line to be buried directly into the earth. In accordance with the National Electric Code, the cable will be buried to a depth of 15-18 inches. This minimizes the risk of damage that may occur to the cable as well as protect a passerby if a short were to occur in the transmission lines. The trench will be constructed and the cable laid in half kilometer increments starting from the generation site and sequentially proceed back to the community. This will reduce the magnitude of erosion that would occur. There exists seven river crossings. At each crossing, the transmission wire will be incased in a schedule 40, 1.5 inch diameter PVC pipe. This pipe will then be suspended in the air by employing wooded base structures as well as overhanging cable that is attached to surrounding trees.

A step-up transformer will be anchored to the foundation of the generation housing near

Chorro Falls and then connected to a high voltage circuit breaker. In the community, a step down generator will be placed in the existing generator house and connected to the current electrical infrastructure.

Appendix L – Cost Analysis

Description	Unit	Quantity	Materials		Equipment		Total
			$/Unit	Cost	$/Unit	Cost	
Mobilization							
Panama City to Port (Truck) Approx. 80 miles	Round Trip	15			$18.00	$270.00	$270.00
Port to Maje Chiman (Boat)	Round Trip	15			$360.00	$5,400.00	$5,400.00
Panama City to Maje Chiman (Truck) Approx. 240 miles	Round Trip	35			$55.00	$1,925.00	$1,925.00
Totals							$7,595.00
Inlet / Forebay							
Rocks	Each	100	$0.00	$0.00			$0.00
Wood	Each	50	$0.00	$0.00			$0.00
PVC Pipe, Schedule 40, Dia 18 in, 10 ft	Feet	4	$38.50	$154.00			$154.00
PVC Pipe Cap, Schedule 40, Dia 18 in	Each	1	$0.53	$0.53			$0.53
PVC Pipe 90° Bend, Schedule 40, Dia 18 in	Each	1	$0.76	$0.76			$0.76
#3 Rebar, 20ft	Feet	16	$3.55	$56.80			$56.80
Cement, 94lb bag	Each	30	$5.00	$150.00			$150.00
Gravel, 20 Cubic Feet	Each	64	$15.95	$1,020.80			$1,020.80
Machete	Each	5			$0.00	$0.00	$0.00
Truper Trunk Buddy Shovel, Fiberglass D-Handle	Each	5			$12.99	$64.95	$64.95
Electric Drill with Drill Bits	Day	1			$65.00	$65.00	$65.00
0.5 in. Perforated Stainless Steel Wire Mesh 36in x 36in	Piece	5	$87.15	$435.75			$435.75
Super Glue: Anchor-Tite Waterproof Epoxy Adhesive	Each	8	$7.90	$63.20			$63.20
Oatey Great White Pipe Joint Compound with PTFE	Each	2	$4.99	$9.98			$9.98
Totals							$2,021.77
Penstock							
18" PVC Pipe, Schedule 40	Foot	670	$38.50	$25,795.00			$25,795.00
18" PVC Pipe Cap, Schedule 40	Each	1	$185.00	$185.00			$185.00
18" Elbow 90° PVC Fitting, Shedule 40	Each	4	$450.00	$1,800.00			$1,800.00
18" Elbow 45° PVC Fitting, Shedule 40	Each	12	$400.00	$4,800.00			$4,800.00
Cement, 94lb bag	Each	80	$5.00	$400.00			$400.00
Gravel, 20 Cubic Feet	Each	64	$15.95	$1,020.80			$1,020.80
#3 Rebar, 20ft	Feet	2	$5.00	$10.00			$10.00
Oatey 32 Oz. Pvc and CPVC Purle Primer	Each	3	$12.00	$36.00			$36.00
Oatey 32 Oz. PVC Cement	Each	6	$9.00	$54.00			$54.00
7 Kw Gas Powered Generator	Week	4			$0.00	$0.00	$0.00
Diesel Gas	Per Gal	100			$4.00	$400.00	$400.00
Super Glue: Anchor-Tite Waterproof Epoxy Adhesive	Each	10	$7.90	$79.00			$79.00

Oatey Great White Pipe Joint Compound with PTFE	Each	5	$4.99	$24.95			$24.95
Jackhammer / Chipper with Air Compressor, 90 lbs	Week	4			$125.00	$500.00	$500.00
Truper Trunk Buddy Shovel, Fiberglass D-Handle	Each	5			$12.99	$64.95	$64.95
Butterfly Shutoff Valve	Each	1	$2,000.00	$2,000.00			$2,000.00
Machete	Each	5			$0.00	$0.00	$0.00
Totals							$37,169.70
Housing							
7kW Diesel Powered	Week	2			$225.00	$450.00	$450.00
Cement, 94lb bag	Each	10	$5.00	$50.00			$50.00
Gravel, 20 Cubic Feet	Each	40	$15.95	$638.00			$638.00
Sand, 1 Cubic Meter	Each	20	$0.00	$0.00			$0.00
Task Force Smooth Hammer	Each	4			$3.98	$15.92	$15.92
Wood	Each	10	$0.00	$0.00			$0.00
Kobalt 12" Finishing Trowel	Each	1			$15.98	$15.98	$15.98
6' x 6' Corrugated Plastic Sheets	Each	8	$6.20	$49.60			$49.60
#3 Rebar, 20ft	Each	5	$5.00	$25.00			$25.00
Tie Wire	Each	10	$0.30	$3.00			$3.00
Poulan 14" 33cc Gas Chainsaw	Each	2			$124.99	$249.98	$249.98
Oregon 2-Pack 14" Replacement Chain	Each	2			$31.96	$63.92	$63.92
Poulan Pro 3-Pack 32 oz Synthetic Blend Bar and Chain Oil	Each	2			$5.68	$11.36	$11.36
Machete	Each	5			$0.00	$0.00	$0.00
24" Elbow 90° PVC Fitting, Shedule 40	Each	1	$862.78	$862.78			$862.78
24" PVC Pipe Cap, Schedule 40	Each	2	$288.67	$577.34			$577.34
24" PVC Pipe, Schedule 40	Feet	12	$74.65	$895.80			$895.80
Totals							$3,908.68
Generator / Turbine / Power							
Canyon Hydro Cross-Flow Turbine	Each	1	$100,000.00	$100,000.00			$100,000.00
Canyon Hydro Gear Drive	Each	1	$10,000.00	$10,000.00			$10,000.00
Canyon Hydro Switchgear/Controls	Each	1	$55,000.00	$55,000.00			$55,000.00
Canyon Hydro Hydraulic Unit	Each	1	$7,000.00	$7,000.00			$7,000.00
Canyon Hydro Inlet Valve	Each	1	$10,000.00	$10,000.00			$10,000.00
Canyon Hydro Dismantling Joint	Each	1	$3,000.00	$3,000.00			$3,000.00
Canyon Hydro Frames	Each	1	$7,000.00	$7,000.00			$7,000.00
Marathon Magna Plus Generator - 362CSL1607	Each	1			$7,210.00	$7,210.00	$7,210.00
Allis Chalmers Transformer 4160V Primary, 480/240V Secondary- Model 11-1340	Each	2			$1,895.00	$3,790.00	$3,790.00
1000ft Armored Aluminum Transmission Wire - Southwire Triple-E 8000 Series, AWG 2/0	Each	40	$2,418.00	$96,720.00			$96,720.00
Bare Aluminum Grounding Wire - AWG 2/0	Each	1	$480.00	$480.00			$480.00

KA Frame 480/240 Circuit Breaker	Each	1	$1,200.00	$1,200.00			$1,200.00
1.5" Diameter Schedule 40 PVC Pipe	Feet	490	$1.56	$764.40			$764.40
Fi-Shock High-Tensile Wire Cutters	Each	2			$21.35	$42.70	$42.70
Machete	Each	5			$0.00	$0.00	$0.00
Truper Trunk Buddy Shovel, Fiberglass D-Handle	Each	3			$12.99	$38.97	$38.97
Jackhammer / Chipper with Air Compressor, 90 lbs	Week	2			$225.00	$450.00	$450.00
Skilled Labor	Day	45			$240.00	$10,800.00	$10,800.00
Professional Engineer	Day	100			$600.00	$60,000.00	$60,000.00
Totals							$373,496.07
Subtotal Estimate							$424,191.22
Subtotal Estimate (including 5% error margin)							$445,400.78
Total Estimate (including 7% tax)							$476,578.84

Appendix M – Maintenance

Hydropower System Maintenance

Some maintenance is required for this system to run properly and continually. These suggestions should be taken into account with the feasibility of this project; if the community can have people checking the system that is 11 kilometers away every week. Record logs should be kept of observations and any changes made to the system.

Weekly Maintenance:

- Check the inlet of the penstock and forebay for debris and ways for it to get clogged
- Walk the length of the penstock for leaks or damage to the piping or force blocks
- In the powerhouse, listen to the running machines for any irregularity
- Check oil levels of machines and bearings
- Record temperature, resistance, and other aspects on running generator
- On way back to the community, check for exposed wire and condition of structures to carry wires over river crossings

Annual Maintenance:

- The system will need to be shut down. With a cross flow turbine this needs to be done slowly so not to ruin any components.
- The forebay should be completely cleaned out and walls scrubbed clean
- Any repairs to damaged pipes or force blocks should be made
- The butterfly valve should be checked and tested
- The turbine needs to be inspected for any damage to parts and replaced if they look worn
- Oil can be replaced
- Check all seals, gaskets, and pads for wear and replace is necessary
- The emergency shutdown should be examined and tested
- The tailrace should be checked for erosion or other problems
- The connections to the generator need to be looked at for wear

- The generator needs to be inspected for wear and preventative electrical failure that would come with the generator
- Connections with the houses in the community should be looked at

About every ten years a more extensive inspection should be conducted, since it is expected that larger pieces, such as pipe or turbine blades may need to be replaced. It is suggested that they have a professional visit the community to do this.

Preventative maintenance means that if something looks worn it should be replaced because it is usually more expensive to replace something after it has already broken and damaged other parts.

Appendix N– Alternatives Analysis

The first option that was investigated was running the current diesel generator for 16 hours a day. Some assumptions made to determine the cost include; the price of gas, the number of gallons transportable per trip to Chepo, and the amount of gas used to make the trip to Chepo and back. Tables 19 and 20 show how the cost was calculated. It should be noted that this was assuming that the cost of gas stayed at the current approximate price of four dollars a gallon.

Table 19: Diesel Generator Cost Analysis

Hours a day of operation (hr.)	16
Gallon of diesel used per one hour (gallons/hr.)	5
Approx. Cost of Diesel (dollars)	$4.00
Transportation cost per gallon of gas (dollars)	$.36
Cost to run per day	$348.80
Cost to run per year	**$127,312.00**

Table 20: Transportation Cost Analysis

Gallons of diesel used per round trip to Chepo	9
Approximate cost of Diesel (dollar/gallon)	$4.00
Cost of Gas used for transportation (dollars)	$360.00
Gallons of diesel transported per trip	1000
Transportation cost for each gallon of gas	**$0.36**

Another alternative that Zapatero investigated was installing solar panels on each of the homes in the community. While in Majé, the team encountered two solar panels mounted on individual homes that provided the resident family with power. In the systems observed, the solar panel charged a battery, similar to a car battery, which was then used at night to provide electricity for lights and small appliances such as televisions. A cost analysis of providing each home with individual household solar panels is provided in Table 21.

Table 21: Solar Cost Analysis

Cost per Solar Panel	$1,500
Homes in the Community	114
Cost Total	**$171,000**

The final option the Team investigated was connecting the community to an existing power distribution system. Alan Foster, a peace core volunteer, has indicated that the community is 15 miles from a highway along which power lines run. The costs analysis for this option can be seen in Table 22 using the same transmission line as proposed for transmission from the micro-hydroelectric system. This cost analysis only represents the cost of the transmission line and does not represent any costs associated with tying into the existing grid or the usage charges the community would pay for the electricity.

Table 22: Connecting to existing Electrical Infrastructure Cost Analysis

Cost of Transmission lines ($/miles)	$ 12,767
Length of Transmission line needed (miles)	15
Total Cost ($)	**$ 191,506**

Appendix O – Energy Saving Opportunities

This appendix shows the progression of the energy management charts.

Data was collected on what appliances community members would want in the future if they had more access to electricity. The Team found how much energy each of these appliances would use and calculated the number of homes using each appliance based on the surveys. This analysis can be found in Table 23.

Table 23: Potential Electrical Consumption of Majé, Chimán Community

Potential Electrical Consumption of Majé, Chimán Community

Appliance	Wattage the Appliance Uses	Percentage of Community Intending to have Appliance	Hours/Day Appliance is Used	Per Home Daily Electricity Consumption (kWh)	Community Daily Electricity Consumption (kWh)	Per Home Electricity Draw (kW)	Community Maximum Electricity Draw (kW)
Street Lights (20)	2000	N/A	12	N/A	24	N/A	2
Home Lights (4)	60	100%	6	0.4	41	0.1	7
Television	133	82%	2	0.3	25	0.1	12
Washing Machine	425	68%	2	0.9	66	0.4	33
Iron	1500	64%	1	1.5	109	1.5	109
Refrigerator	725	18%	24	17.4	361	0.7	15
Computer	120	36%	4	0.5	20	0.1	5
Power Tools	1000	14%	5	5.0	78	1.0	16
Stove	2800	9%	3	8.4	87	2.8	29
Fan	200	5%	5	1.0	5	0.2	1
Totals				35.3	815	6.963	229

From this, Table 24 was constructed to show each hour of the day and the power usage at that time. Even if the system outputs 78 kW, it is still enough for each hour except the one hour in which approximately half the community is ironing their children's school clothes before they go to school in the morning.

Irons are one of the most energy intensive appliances and because of the wide desire for them; they are expected to cause the largest energy problem. In order to remedy this, the Team suggests the community schedule the times of iron use. A community schedule needs to be implemented with multiple time slots in which families can use their iron. While the team believes a schedule would be the best way to monitor and control iron usage, it could also prove to be a problem to the women who have other chores around the house as well. They could also look into cheaper forms of irons, such as the non-electric irons which work by being warmed up in a stove or fire. The women are generally cooking at the times the Team expects the irons to be used and the three-stone-system stoves could be used to heat the irons while the women are cooking.

The Team also suggests a laundromat where there would be about five washing machines and three irons. There would be one on each side of the community for easier access. This would decrease the community energy usage at those times and naturally limit the amount of irons and washing machines running at one time. It also makes access to washing machines more economical for everyone in the community. However, there is a concern that women would use the river instead of waiting for an open machine.

Table 24 also shows that a small percentage aspire to having a refrigerator which would be running all the time. If that percentage would grow to even half, it would threaten their electrical capacity. The computers were calculated for the purposes of the school and certain community members who would like to utilize them for grant writing and applying for governmental funding. The power tools for making wooden sculptures would be used more periodically than what is displayed because of the large amount of artists in the community and using them at different times in the day. The Team would advise using the tools during the middle of the day when washing machine use is at a minimum and when the community is resting due to the afternoon rain.

Table 25 shows the power usage when some of the mentioned ideas, including the laundromat and power tool scheduling, are utilized.

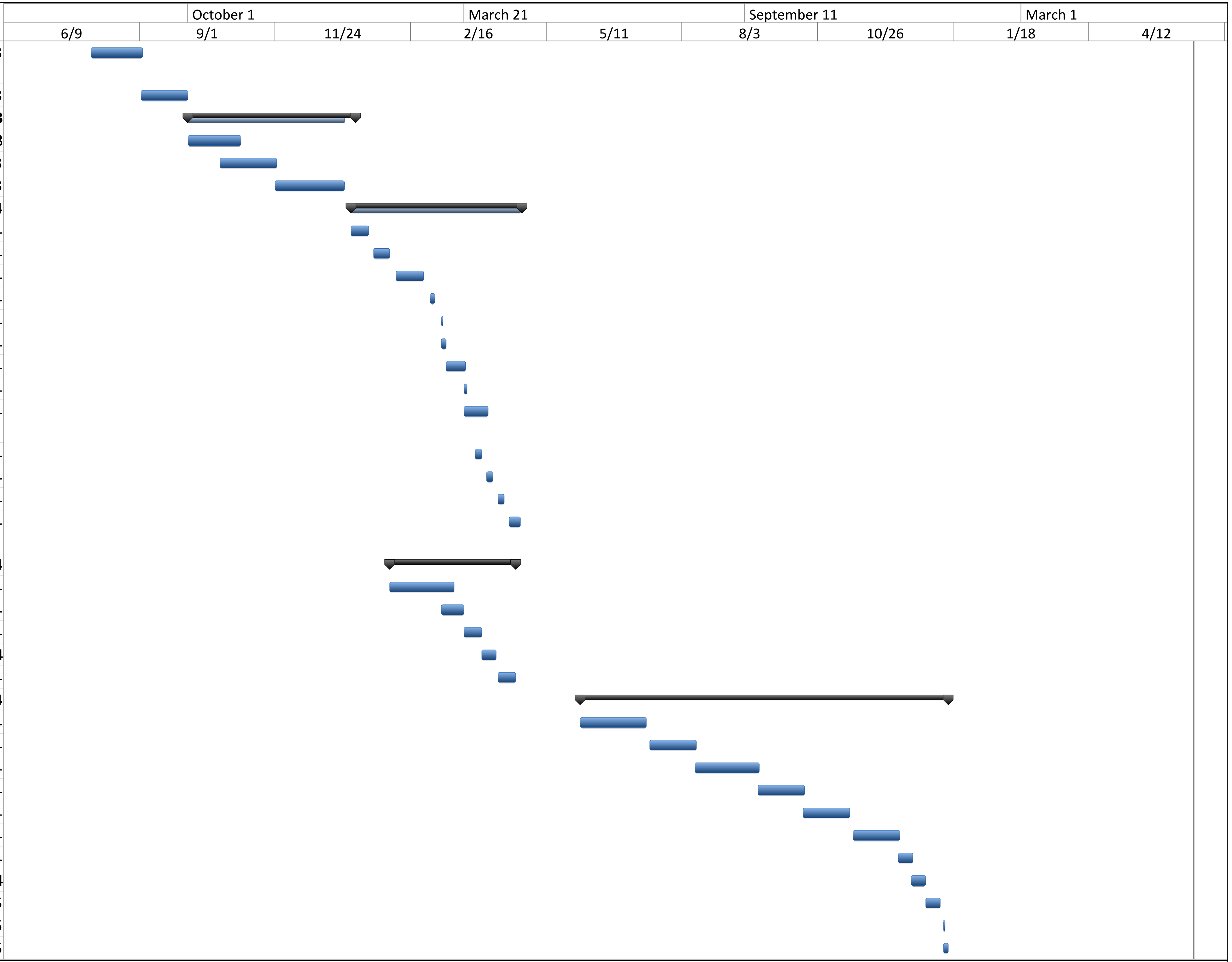
Table 24: Energy uses in 24 hours' time using data from surveys of community members

Appliance	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am	1am	2am	3am	4am	5am
Street lights													2	2	2	2	2	2	2	2	2	2	2	2
Home lights												7	7	7	7								7	7
Television															12	12								
Washing machine			33	33																				
Iron		109																						
Refrigerator	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Computer						5	5			5	5													
Power Tools									16	16	16	16	16											
Stove	29						29							29										
Fan							1	1	1	1						1								
Totals	**44**	**124**	**48**	**48**	**15**	**20**	**50**	**16**	**32**	**37**	**36**	**38**	**40**	**52**	**36**	**30**	**17**	**17**	**17**	**17**	**17**	**17**	**24**	**24**

Table 25: More Optimal energy use in 24 hours

Appliance	6am	7am	8am	9am	10am	11am	12pm	1pm	2pm	3pm	4pm	5pm	6pm	7pm	8pm	9pm	10pm	11pm	12am	1am	2am	3am	4am	5am
Street lights													2	2	2	2	2	2	2	2	2	2	2	2
Home lights												7	7	7	7								7	7
Television															12	12								
Washing machine			33	33																				
Iron		109																						
Refrigerator	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Computer						5	5			5	5													
Power Tools									16	16	16	16	16											
Stove	29						29							29										
Fan							1	1	1	1						1								
Totals	**44**	**124**	**48**	**48**	**15**	**20**	**50**	**16**	**32**	**37**	**36**	**38**	**40**	**52**	**36**	**30**	**17**	**17**	**17**	**17**	**17**	**17**	**24**	**24**

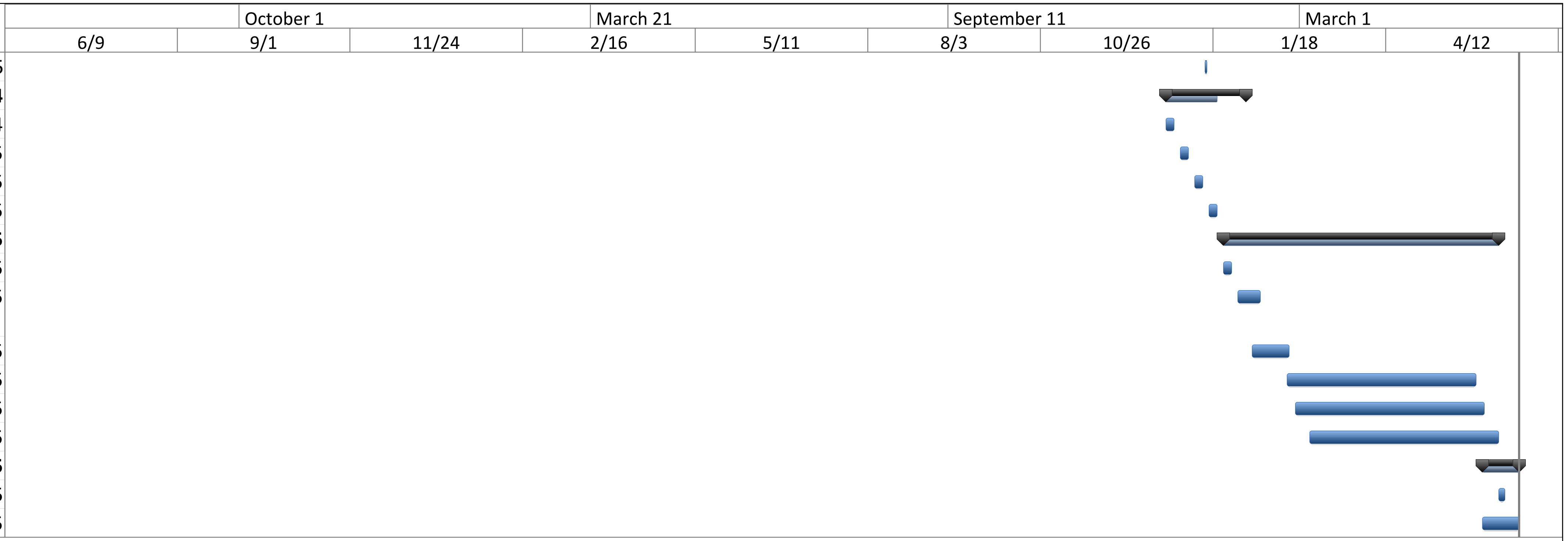
ID	ℹ	Task Name	Duration	Start
1	▦	Determine Route of Road and Penstock	22 days	Fri 8/2/13
2	▦	Order all Materials Needed	21 days	Mon 9/2/13
3		**Path**	**78 days**	**Tue 10/1/13**
4	▦	Clear Brush	25 days	Tue 10/1/13
5	▦	Tree Removal	27 days	Mon 10/21/13
6	▦	Gravel	32 days	Sun 11/24/13
7		**Housing**	**76 days**	**Fri 1/10/14**
8	▦	Clear Brush	7 days	Fri 1/10/14
9	▦	Clear Trees	6 days	Fri 1/24/14
10	▦	Haul Materials	11 days	Fri 2/7/14
11	▦	Slab Form	1 day	Fri 2/28/14
12	▦	Rebar	1 day	Fri 3/7/14
13	▦	Pour Slab	1 day	Fri 3/7/14
14	▦	Cure Concrete	10 days	Mon 3/10/14
15	▦	Remove Form	1 day	Fri 3/21/14
16	▦	Construct Load Bearing Columns and Side Walls	11 days	Fri 3/21/14
17	▦	Erect Columns	2 days	Fri 3/28/14
18	▦	Erect Side Walls	2 days	Fri 4/4/14
19	▦	Assemble Roof	2 days	Fri 4/11/14
20	▦	Clear Area of remaining materials	5 days	Fri 4/18/14
21		**Materials Haul**	**56 days**	**Mon 2/3/14**
22	▦	Piping	30 days	Mon 2/3/14
23	▦	Thrust Block Concrete	10 days	Fri 3/7/14
24	▦	Rebar	7 days	Fri 3/21/14
25	▦	Metal Mesh	7 days	Tue 4/1/14
26	▦	Misc.	7 days	Fri 4/11/14
27		**Inlet / Penstock / Forebay**	**164 days**	**Sun 6/1/14**
28	▦	Clear Path	31 days	Sun 6/1/14
29	▦	Lay Piping Out	21 days	Mon 7/14/14
30	▦	Construct River Diversion	30 days	Mon 8/11/14
31	▦	Dig Area of Forebay	21 days	Fri 9/19/14
32	▦	Construct Channel to Forebay	21 days	Fri 10/17/14
33	▦	Construct Forebay	21 days	Mon 11/17/14
34	▦	Connect Piping Together	7 days	Mon 12/15/14
35	▦	Anchor Piping to Ground	7 days	Tue 12/23/14
36	▦	Construct Thrust Blocks	7 days	Thu 1/1/15
37	▦	Test System	1 day	Mon 1/12/15
38	▦	Let Penstock Pipe Dry Out	3 days	Mon 1/12/15



Project: Zapatero Construction.m
Date: Wed 12/12/12

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]	

ID	ℹ	Task Name	Duration	Start
39	▦	Cap Penstock Pipe	1 day	Wed 1/14/15
40		**Generator / Turbine**	**27 days**	**Fri 12/26/14**
41	▦	Haul Turbine and Generator	2 days	Fri 12/26/14
42	▦	Haul Misc Materials	2 days	Fri 1/2/15
43	▦	Connect Turbine to Penstock	2 days	Fri 1/9/15
44	▦	Connect Generator to Turbine	2 days	Fri 1/16/15
45		**Power Lines**	**96 days**	**Fri 1/23/15**
46	▦	Locate Points of Crossings	2 days	Fri 1/23/15
47	▦	Haul Materails for Crossing to Crossings	7 days	Fri 1/30/15
48	▦	Construct Line Crossing	12 days	Fri 2/6/15
49	▦	Dig Half Kilometer Segment	66 days	Mon 2/23/15
50	▦	Lay Line	66 days	Fri 2/27/15
51	▦	Cover Line	66 days	Fri 3/6/15
52		**Clean Up**	**13 days**	**Fri 5/29/15**
53	▦	Test System	2 days	Sat 6/6/15
54	▦	Remove all equipment	13 days	Fri 5/29/15



Project: Zapatero Construction.m
Date: Wed 12/12/12

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	]		